1

Identification of the Initial Entity in Granular Route Directions

Martin Tomko[1] and Stephan Winter[2]

[1] CRC for Spatial Information, Department of Geomatics, University of Melbourne, Victoria 3010, Australia `m.tomko@pgrad.unimelb.edu.au`
[2] Department of Geomatics, University of Melbourne, Victoria 3010, Australia `winter@unimelb.edu.au`

Summary. Current navigation services assume wayfinders new to an environment. In contrast, our focus is on route directions for wayfinders who are familiar with the environment, such as taxi drivers and couriers. We observe that people communicate route directions to these wayfinders in a hierarchical and granular manner, assuming some shared knowledge of the environment. These route directions do not focus on the route but rather on the destination. In this paper we solve the first problem of automatically generating route directions in a hierarchical and granular manner: finding the initial entity of such a communication. We propose a formal model to determine the initial entity, based on Grice's conversational maxims, and applied to a topological hierarchy of elements of the city. An implementation of the model is tested for districts in a political subdivision hierarchy. The tests show a reasonable behavior for a local expert, and demonstrate the efficiency of granular route directions.

1.1 Introduction

Current navigation services provide turn-by-turn route directions to human users. In contrast, route directions given by people are significantly different [13, 12, 4]. For example, people *chunk* route segments together, depending on various structural characteristics of the route [14], and they refer to specific salient elements in the environment, such as landmarks, paths, nodes, districts and edges [16].

In particular, people usually adapt route directions to the level of familiarity with the environment shared by the wayfinder. If direction givers can assume that the recipients have some familiarity with the environment, they initiate route directions by reference to an element at a coarse level of granularity replacing the destination, such as 'Ikea . . . is in Richmond'. They expect that the recipient shares knowledge of the environment at least at this coarse level, and will be able to find a way to this element autonomously. The direction givers continue then with increasingly detailed directions to the destination starting from this initial element, such as 'In Richmond, at the town hall, take . . . '.

The above mentioned elements of the city form a functional hierarchy of levels of granularity, and exploiting this property in route directions produces what we call *granular route directions*. We argue that current navigation services with their detailed turn-by-turn directions serve only a subgroup of wayfinders with low familiarity with the environment. A large group of potential users of navigation services are neglected: people living in a city and having a general idea of its structure. People in this group may perceive turn-by-turn directions patronizing, and hence, they are not satisfied with the quality of service. They are better served by granular route directions.

In this paper we study the initial entity of granular route directions for recipients who are familiar with the environment. We are interested in determining the element of the city that has to be included as the initial entity in such a communication. This element needs to be shared by both agents' mental models. Our hypothesis is that the choice of the element depends on the hierarchical relationship between the start and the destination of the route. The hypothesis builds on the concept of *relevance*, as defined in maxims for communication acts first identified by Grice [8]. These maxims postulate that information conveyed to the recipient should be neither too coarse nor too detailed.

We propose to deduce the relevance of elements of the city to the route from their position in the hierarchy in relation to the start and destination of the route. We formulate conditions that determine the amount of information to be communicated to the recipient, and integrate these conditions into a formalized model. This model is further translated into an executable specification such that its behavior can be demonstrated and tested. Furthermore, specific tests for districts are introduced and explained. The discussion of the test results enable parallels to be drawn for the extension of the model for the remaining elements of the city: paths, landmarks, nodes, and edges.

This paper is structured as follows: Section 1.2 introduces the basic theoretical foundations from spatial cognition and communication theory upon which we build our proposed model. We then develop our model of granular route directions (Section 1.3), which is formalized for implementation in Section 1.4. The algorithm for the identification of an initial entity is formalized in Section 1.5. The test cases are described and discussed in Section 1.6, and followed by conclusions in Section 1.7.

1.2 Route Communication

1.2.1 The Structure of Urban Environments

People living in an urban environment learn the spatial layout of that environment through frequent, repetitive interactions, such as wayfinding [17]. The accuracy of the acquired knowledge increases with the continuing interaction with the environment, and so increases the accuracy of the agent's mental model [26]. The evidence that such models contain hierarchically organized knowledge was demonstrated by Hirtle [11, 10]. Hierarchical conceptualization of space enables granular spatial reasoning, for example in wayfinding on a hierarchic path network [25], as well as communication of route knowledge in a granular manner [28, 20]. In comparison to these works, our approach is different by not communicating the full path from the start to the destination, but instead try to describe the destination in a granular manner.

1.2.2 Communicating Route Directions

Current navigation services provide no direct interaction with the recipient. The communication situation corresponds to indirect human communication: route directions are *read* by the recipients, who then try to realize their understanding of the directions in the physical environment. In this sense route directions form *narratives*, and direction givers are *narrators* [27].

Human communication of route directions has been the object of investigations for decades now [13, 12, 7, 2, 4, 15]. Despite that, there is so far no study that specifically looks into human route communication to wayfinders familiar with the environment. Our observations and examples are, however, consistent with those described in [23, 20].

Past research of direct route communication explored collaboration on references to objects, either mutually known and visually accessible by the recipient [1, 9], or unknown and inaccessible by the recipient [5]. Unlike these studies, the emphasis of this paper is on the selection of the element communicated by a narrator from the set of available elements. The process described is still an indirect one, as the narrator infers which element to refer to from context and builds a narrative from that suggestion.

1.2.3 Relevance

In his seminal work, Grice [8] made a contribution to the studies of pragmatics by formulating four maxims of conversation, well applicable to effective and efficient information transmission: the maxim of quality, quantity, relevance and clarity. Route directions are a specific type of information communication which is deeply pragmatic and rich in content. This paper explores the impact of the maxims of *quantity* ("make your contribution as informative as required by the purpose of the exchange; do not make your contribution more informative than is required."), *relevance* ("be relevant.") and *clarity* ("avoid obscurity of expression; avoid ambiguity; be brief (avoid unnecessary prolixity); be orderly.") on route directions generation. We assume that the maxim of *quality* ("do not say what you believe to be false; do not say that for which you lack adequate evidence") is respected, as a prerequisite for usable route directions.

1.3 Route Communication to Familiar Wayfinders

1.3.1 Relevance in Route Directions

Information that is too coarse is of no value for the recipient. Imagine a passenger entering a taxi at Melbourne University for a trip to the train station. If he says 'To

Melbourne, please' the *surprisal value* of this information—being in Melbourne and going to Melbourne—is low [22, 29]. In a different context, for instance in Geelong (next to Melbourne), the same order makes perfect sense to the taxi driver, at least for a first leg of the trip. If a message has the appropriate surprisal value, its *pragmatic information content* [6] is maximal and thus it has high *relevance* for the recipient [24].

In such directions, direction givers refer to an element of the city [16] as small as possible–here, a district. The choice is further limited by the other constraints–the necessity to refer always to shared concepts and to avoid ambiguity. Ambiguity occurs if at a level of granularity several possible references exist. For example, the taxi passenger from Melbourne University should not say 'To the train station, please': there are several of them close by. The surprisal value is too high and the taxi driver is confused.

Thus, a direction giver strives to provide a reference to the finest element presumably shared with the recipient that just avoids ambiguities. This phenomenon was previously observed by Rumelhart in 1974 (as described by Shanon [23]). Shanon then suggests topology as selection criteria for appropriate references.

1.3.2 Granular Route Directions

Granular route directions represent a specific case of referring expressions as defined by [3]:"[A referring expression is] . . . an expression uniquely identifying a specific object". They represent a concatenation of multiple references to entities with an increasingly fine level of detail. This zooming in route directions was previously observed by Plumert *et al.* [20, 21].

Granular route directions have the potential to be significantly shorter than turn-by-turn directions, with the length measured by the number of references. The difference increases with the length and complexity of the route. For example, a current navigation system needs 18 turn-by-turn directions from Melbourne Airport to 'Turnbull Alley' in the city center. A system using granular route directions could instead deliver a human-like message: "In the city, off Spring Street, opposite the Parliament', consisting of three entities.

Formulating the basic principles of selection of spatial entities from a hierarchical structure of the city enables to construct granular route directions. Human route directions are a mixture of references to various elements of the city, with complex interdependencies. This paper starts the exploration of the subject by considering only a single type of element, districts. Considering a hierarchical partition of the city, we define the conditions for selecting the initial entity of granular route directions, i.

A granular communication process depends on the identification of the context, which is often sufficiently clear in human communication. Consider the taxi scenario again: the passenger concludes from the situation that the driver is familiar with the city. The passenger may also know from experience that taxi drivers typically do not know specific destination addresses. Furthermore, the passenger and driver both share the knowledge of the start of the route: their current location.

In the indirect communication situation of a navigation system the system has to presume that the wayfinder shares the knowledge of some elements of the environment. It can do so by profiles of users, or profiles of standardized application areas. Furthermore, we expect that future systems will be able to conduct dialogs, and thus, can correct wrong assumptions.

1.3.3 Granular Route Directions in Communication

The quest to keep the amount of information communicated to the necessary minimum provides a means to start the route description at the maximum possible detail and still keep the certainty of the information transmitted, all in accordance with Grice's maxims [8]. If the wayfinder is familiar with the environment, the narrator will refer to this shared knowledge, in order to keep the amount of transmitted information low. The narrator will typically refer to a well-known element of the city in the proximity or containing the destination. This element is at the finest level of shared knowledge, and its communication would be sufficient and most effective.

In some cases, such as those of entities with ambiguous names, the narrator needs to refer to elements at coarser levels in the hierarchy, to uniquely identify the referent. For example, when referring to a destination close to the opera building in Sydney, one could just refer to the *Opera*, and for any wayfinder in Sydney this would be sufficient. If the start of the route is not in Sydney, a disambiguation is necessary, by referring to the *Sydney Opera*. This is a granular route description including two levels of granularity: *Sydney* and *Opera*. A similar process of referring in a document hierarchy was described in [18]. In this work, the authors referred to the effect caused by such ambiguous references as *lack of orientation*. Consider Figure 1.1, which

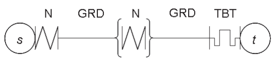

Fig. 1.1. Negotiations about references and in route direction in the context of the route (see text).

represents the complete communication process of the narrator and the wayfinder. The spatial relation of the start s and the destination t of the route provides sufficient clues to start the granular route description. An insufficient overlap of the knowledge of the wayfinder and the narrator may require a collaborative identification of the destination in a negotiation segment (N). This process iteratively enables the narrator and the wayfinder to find a shared element at a certain hierarchical level in their respective mental models of the environment.

A similar negotiation process occurs upon reaching the finest shared element, and is followed by turn-by-turn directions. This can also occur in the middle of the route directions, in the case of structural differences in the mental models of the narrator and the wayfinder.

1.4 A Formal Model for the Initial Element Identification

1.4.1 Model Constraints and Assumptions

Building on the representation theory of Worboys [29], to reach consensus between the narrator and the wayfinder the representation of the information in the narrator's domain N has to be transmitted through a communication process and matched to the correct representation in the wayfinder's domain W (Fig. 1.2). Both N and W

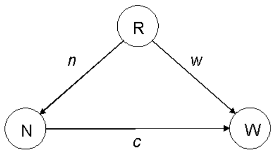

Fig. 1.2. Domain formation and matching process (see text).

are subsets of the domain R, ($N, W \subseteq R$), which represents the reality. The domains N and W are mental models of the reality, which can be incomplete and imperfect with regard to R, as they are constructed by learning through interaction with the environment. We call these mapping processes n (reality $\mapsto$ narrator) and w (reality $\mapsto$ wayfinder) respectively.

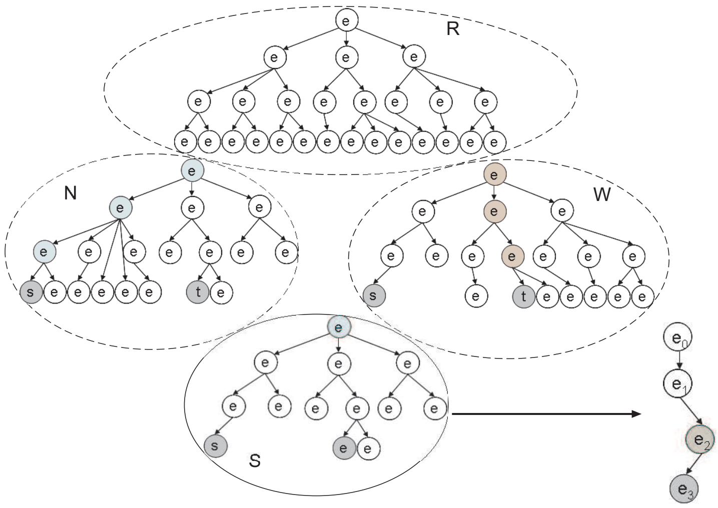

Fig. 1.3. Domain S and the route hierarchy reconstruction (see text).

Lets consider the Figure 1.3. The domain R, and therefore also N and W, consist of elements e, of any of Lynch's five types of elements of the city. These elements are organized hierarchically in levels l. Note that the hierarchies h_N and h_W are not necessarily subtrees of the hierarchy h_R, ($\diamond(h_N, h_W \subseteq h_R)$). As we can see in the hierarchies of the domains N and W, differences in granularity levels between the reality and the mental models occur, including omissions of elements. Therefore, the hierarchies h_N and h_W are not necessarily identical ($\diamond(h_N \neq h_W)$). The intersection of the domains N and W is the subset of elements S that are shared by both agents ($N \cap W = S$) with identical tree structure h_S.

During the communication, a process c, ($c : e_N \mapsto e_W$), representing the communication, associates respective elements from the domain N to the domain W. To reach consensus between the narrator and the wayfinder, the process n and the process w have to associate the respective representations e_N and e_W of an element e_R. If these processes are successful, the agents in effect exploit the elements of the domain S in the communication (Fig. 1.3).

In our model, we assume the preservation of relative ordering of elements in the hierarchies (if $l_N(e_1) > l_N(e_2)$ then $l_W(e_1) \geq l_W(e_2)$). If an element e is present in the mental model of the wayfinder and the narrator, its place in the hierarchical structure of the domains N and W is such that the relative ordering between the adjacent elements in the tree is preserved. A violation of the relative ordering condition would result in an incompatible mental model (e.g. cities composed of countries). If this condition is not met, the narrator and the wayfinder have to engage in communication about the reference made.

As an implication, the hierarchies of elements in the two domains may have different depths, e.g., be flatter or deeper. Any elements not shared by both domains N and W can only be found on the finest levels of the respective hierarchies.

In order to describe the whole route, several elements of descending levels of granularity have to be identified and matched through the communication process c. Let us call this set of elements C, ($C \subseteq S$). This process leads to the reconstruction of a subtree h_C of the hierarchy h_S. The initial entity referred to in granular route directions is a member of the subtree h_C (element e_2 in Figure 1.3).

Worboys [29] considers the different contexts of two agents engaged in communication. In our case we limit context formally to the knowledge of the agents (narrator and wayfinder), represented by domains with internal structure h_N and h_W. These contexts are, in general, different. A typical example is the situation where the narrator knows the destination, but the wayfinder does not (otherwise route directions are not necessary). The narrator, initiating a wayfinding communication, anticipates the context of the wayfinder. In order to construct successful granular route directions, the conditions on the two domains and their internal structures need to be met, and the context of the wayfinder is correctly anticipated. Otherwise, the agents will enter in a new cycle of negotiation, as discussed in Section 1.3.3.

1.4.2 Initial Element Identification

We now apply the basic principles described earlier to the identification of the initial entity i of the granular route directions. These principles are grounded in information relevance and explore the topological relation of the start (s) and target (t) element of the route within the hierarchy h_S (Figure 1.3).

The selection is grounded in a translation of Grice's maxims into the assessment of the information value brought by inclusion or omission of a certain element from a hierarchical partition of space into route directions. Possible topological relations between the start and destination elements of the route in a hierarchical tree structure were analyzed. The topological relationships tested consider only the inside and the boundary of an element (district). Two districts are considered neighbors only if they share a boundary, a one dimensional space. The following conditions can be defined (applies to the selection in a set of *districts*):

1. start and destination must be member of the shared set of elements ($s, t \in S$);
2. start and destination must not be identical (but may meet, be neighbors)($s \neq t$);
3. the start and the destination should not be neighbors ($\partial s \cap \partial t = \emptyset$));
4. the start and the destination should not have neighboring direct superordinate elements ($\partial Sup_s \cap \partial Sup_t = \emptyset$).

The conditions 2 and 3 must be separated, as they verify a different behavior. If s and t are identical (and thus they have overlapping interiors and boundaries), it is not possible to construct route directions (a route is two dimensional and thus requires a star and a target). If s and t are neighbors, route directions are possible, but the topological distance between the specification of the start and the specification of the target is insufficient to generate *granular* route directions.

Thus, the third and the fourth conditions excludes cases where the start and destination are too close in the hierarchy and turn based directions should be applied.

Consequently, sets $Super_t$ of superordinate elements of t and $Super_s$ of superordinate elements of s can be formed. The set $Super_t$ is a candidate set for the initial element i. Superordinate elements of an element e are elements of coarser granularity than e that have e as descendant. This property is transitive. From now on, the notation Sup_e will be used for a parent element of e. The element i is retrieved from the candidate set $Super_t$ ($i \in Super_t$). Further conditions apply for selection of the element i from the candidate set:

5. element i must not be shared by $Super_s$ and $Super_t$, ($i \notin Super_s$);
   This condition excludes elements that are superior to both the start and the destination, and so do not add information value to the route directions.
6. element i should not be neighbor with an element in $Super_s$ ($\partial i \notin S$);
   This condition excludes elements that are in a neighboring relation with an element of the hierarchy $Super_s$ ($e \cap Sup_i \neq \emptyset, e \in Super_s$). This assures a minimal topological distance between the initial reference and the start s, in order to only add information with sufficient surprisal potential (and thus adhering to the maxim of information quantity). If the condition is not fulfilled, an element one step deeper in the hierarchy should be employed .

These conditions assure that the information communicated through the element i has value for the wayfinder. In condition 5, the wayfinder would get information that was too coarse. For example, *Australia* is not an appropriate initial element for route directions from *Sydney* to *Melbourne Central Business District*, as it is a superordinate element of both.

The second condition assures that the information is detailed enough–mentioning *Victoria* would not provide our wayfinder enough information either. In principle, the granularity level of the resulting element i would be correct, but there is not enough topological distance between the destination and the start element to justify its inclusion. Note that *New South Wales* and *Victoria* are in our hierarchy neighbors, and *Victoria* is a direct superordinate element of *Melbourne* (Fig. 1.4). And indeed, telling somebody traveling from *Sydney* to *Melbourne* that she has to go to *Victoria* does not provide any information value. In this case, the starting element of the granular route directions should be *Melbourne*. This element is not a neighbor of any element of the hierarchy of the start element, nor of any of its superordinate elements. Any coarser level of granularity would not satisfy these conditions and would result in a route description violating Grice's maxim of relevance. The conditions mentioned above assume that there is no element with two children with the same identifier. It is, however, possible to have a repetition of identifiers within the domain.

The conditions 1–6 are serialized in an algorithm (Alg. 1), and further implemented in Haskell (Section 1.5).

Algorithm 1: Initial element i identification (*district hierarchy*)

Data: The urban hierarchical structure of districts: domain S, starting district s and destination district t of the route

Result: The initial element i for route directions from s to t

case $(s, t \notin S) \vee (i \neq s) \vee (i \cap s = 0) \vee (i \neq s)$
  Error: cannot generate granular directions, lack of relevant elements or bad topological context

otherwise
  Construct candidate set $Super_t$ and $Super_s$, where $Super_s = [s, s_1 \dots s_m]$, where $l_{s_m} = 0, l_{s_x} = m - x$; $Super_t = [t, t_1 \dots t_n]$, where $l_{t_n} = 0, l_{t_y} = n - y$;
  Compare hierarchies h_{Super_s}, h_{Super_t} such that $(\forall s_x, t_y \in (Super_s \times Super_t))$:
  if $(Sup_{s_x} = Sup_{t_y}) \vee (Sup_{s_x} \cap Sup_{t_y} \neq \emptyset)$ **then**
    Return list T of t_y;
  Retrieve the element t_y of T with the finest granularity level $(l_{t_y} = max)$;
  Return $i = t_y$;

1.5 Model Implementation

Algorithm 1 is now implemented in Haskell [19]. Haskell is a purely functional programming language that enables implementation of an executable version of the algorithm, with a focus on the *what* instead on the *how*. Efficiency of our code is neglected, however, some efficiency is gained by the lazy execution paradigm of Haskell.

We call the main analytic function of the program `rd` (for *route directions*). The function first verifies the four conditions in Section 1.4.2:

```
rd :: String -> String -> [Object] -> String
rd a b c
| (!testObj a c || !testObj b c)           = error
| (a == b)                                 = error
| testShareBounds (obj a c) (obj b c)      = error
| (super (obj a c)) == (super (obj b c))   = error
| otherwise describe a b c
```

The custom data type `Object` contains a name for each object (a string), and other parameters. Names of the objects are identifiers searched for in the above functions. For example, the function `obj` returns the object specified by a name from the list of all objects.

The function `rd` requires the names of the start and destination elements of the route as input parameters (in our case districts, but in principle also other elements of the city), as well as the name of the list of objects, `objects`, on which the selection will be performed. Afterwards, the program reconstructs the superordinate hierarchies of the start and destination elements, bound on the one side by these two elements, and on the other by the root element of the hierarchical tree. These hierarchies are represented as lists of objects, which are then compared according to the conditions 5 and 6 (see Section 1.4.2). The comparison returns a list of objects—a subset of elements of $Super_t$. The first—coarsest—element of this list, is the element i (Alg. 1).

```
describe :: String -> String -> [Object] -> String
describe a b objlist = fetchName (compareHierarchies
    (findObjects (obj a objlist) objlist)
    (findObjects (obj b objlist) objlist))
```

where

```
compareHierarchies :: [Object] -> [Object] -> Object
compareHierarchies start []     = error
compareHierarchies [] dest      = error
compareHierarchies start dest   = head [y |
    x<-start, y<-target,
    super x == super y || superShareBounds x y]
```

The element i is the initial entity of a sequence of granular route directions. A deeper illustration of the principles summarized in the algorithm and implemented in the program follows.

1.6 Model Verification and Testing

We have devised a set of tests to verify the behavior of the algorithm. The test data vaguely mirrors the spatial layout of the relations between some *administrative districts* in Victoria and New South Wales, Australia (Fig. 1.4). With this data we will assess the results of the algorithm for plausibility. Our effort is focused on verifying that the conditions for retrieving the elements from the structure of the city provide an amount of information similar to that provided by humans, as drawn from empirical evidence and a small reference corpus from co-workers. More extensive comparison by human subject testing is needed in the future.

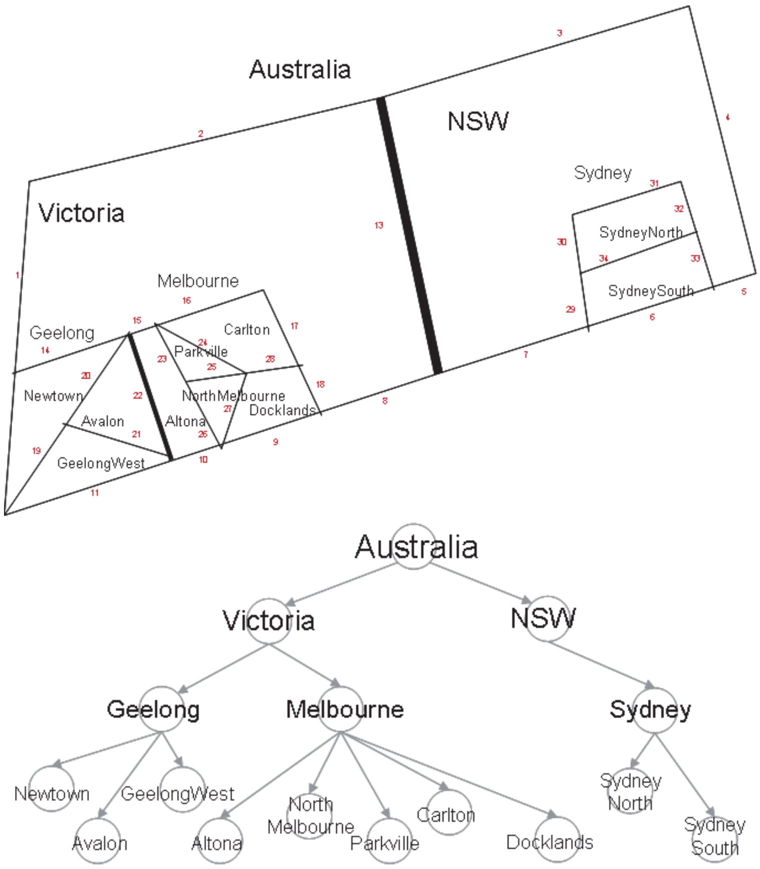

Fig. 1.4. Test data set.

For the test, the `Object` data type for *districts* is structured as follows:

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

A district *Melbourne* would have the form (cf. Fig. 1.4):

```
ob4 = Object 2 "VIC" "Melbourne" [22,15,16,17,18,9,10]
```

expressing that Melbourne is of level 2 in the given hierarchy, is part of Victoria and is bound by a polygon of some named edges.

The following eight test cases were devised, to test all the possible eventualities. Each test case consists of a pair of input districts (start and destination) from arbitrary hierarchical levels, and the list of all objects of the hierarchy, `os`. Results of each test case are shown behind the hyphen in each line:

```
rd "SydneyNorth" "Parkville"   os - "Melbourne"
rd "Parkville"   "SydneySouth" os - "Sydney"
rd "Carlton"     "GeelongWest" os - "GeelongWest"
rd "SydneyNorth" "Melbourne"   os - "Melbourne"
rd "SydneyNorth" "Park"        os - "input␣not␣in␣os!"
rd "SydneyNorth" "SydneyNorth" os - "start␣=␣target!"
rd "SydneyNorth" "SydneySouth" os - "neighbors;␣TBT␣dirs"
rd "Parkville"   "Docklands"   os - "same␣super;␣use␣TBT"
```

This set of tests checks the behavior of different possible topological relations between the input objects. Let us have a detailed look at the operation of our test function `rd`, using the first case as an example. The function first tests the inputs against the basic conditions, and if fulfilled, the search for the initial element starts. The hierarchies of the superordinate elements of the start and the destination are then reconstructed, resulting in the following lists:

```
[Object 3 "Sydney" "SydneyNorth" [30,31,32,34],
Object 2 "NSW" "Sydney" [6,29,30,31,32,33],
Object 1 "Australia" "NSW" [3,4,5,6,7,13],
Object 0 "World" "Australia" [1,2,3,4,5,6,7,8,9,10,11,12]]
```

and

```
[Object 3 "Melbourne" "Parkville" [23,24,25],
Object 2 "Victoria" "Melbourne" [22,15,16,17,18,9,10],
Object 1 "Australia" "Victoria" [1,2,13,8,9,10,11,12],
Object 0 "World" "Australia" [1,2,3,4,5,6,7,8,9,10,11,12]]
```

The elements of these lists are then compared on a one–to–one basis through the function `compareHierarchies`, applying the conditions mentioned in Section 1.4.2. We are looking for a list of objects from the list of the superordinate elements of the destination that satisfies these conditions. The resulting set is:

```
[Object 2 "Victoria" "Melbourne" [22,15,16,17,18,9,10],
Object 1 "Australia" "Victoria" [1,2,13,8,9,10,11,12],
Object 0 "World" "Australia" [1,2,3,4,5,6,7,8,9,10,11,12]]
```

Finally, the first element of this list, *Melbourne*, is returned as the element of finest granularity. This element is proposed as the initial element of granular route directions from *Sydney North* to *Parkville*. And indeed, when asking for route directions from a starting location in Sydney North (a suburb of Sydney, New South Wales), to a location in Parkville (a suburb of Melbourne, Victoria), a familiar wayfinder is likely to expect Melbourne as the element representing the initial entity of route directions. This element provides the optimal trade off of information value and length of the route directions, is not ambiguous and omits irrelevant information. Remaining test cases also produce plausible results, as can be checked with Figure 1.4 by the interested reader.

1.7 Conclusions

This paper contributes to bridging the gap between the natural, human way of communicating route directions in a granular manner, using various elements of the urban environment, and the turn-by-turn approach implemented by most of the current navigation services. We focus on the determination of the initial element usable for granular route directions, building on the principles of information content relevance. Topological relations between the member elements of the start and destination element hierarchies are analyzed to identify this element. The conditions for analyzing the hierarchical structures are formalized, and the algorithm is then implemented in Haskell.

The test in this paper focuses on the analysis of district hierarchies, districts being one of the elements of the city most frequently included in human route descriptions, and often the first reference in granular route directions. Our approach enables the use of any type of region, be it with crisp or vague boundaries, as long as they can be organized in a hierarchy. Based on the inputs and the hierarchy, the algorithm returns the initial element. The formalized topological conditions conform with the observations made previously by Rumelhart and explored by Shanon [23], and conform to the findings in the area of hierarchical spatial reasoning. Our further work will strive to integrate the remaining elements, especially paths and landmarks. This will also lead to a more natural definition of topological relationships, depending also on connectivity, and not only on simple relationships between the interiors and boundaries. Connectivity analysis can also provide means to define district hierarchies better reflecting the inherent structure of a city. The analysis of such district hierarchies can provide the basis for identification of the remaining elements, as some dependencies between districts and landmarks [10] or paths were identified.

Acknowledgements

The work has been supported by the Cooperative Research Centre for Spatial Information, whose activities are funded by the Australian Commonwealths Cooperative Research Centres Program.

References

1. H. H. Clark and D. Wilkes-Gibbs. Referring as a Collaborative Process. *Cognition*, 22:1–39, 1986.
2. H. Couclelis. Verbal directions for way-finding: Space, cognition and language. In J. Portugali, editor, *The Construction of Cognitive Maps*, pages 133–153. Kluwer, Dordrecht, 1996.
3. R. Dale. *Generating Referring Expressions: Constructing Descriptions in a Domain of Objects and Processes.* ACL-MIT Series in Natural Language Processing. MIT Press, 1992.
4. M. Denis, F. Pazzaglia, C. Cornoldi, and L. Bertolo. Spatial Discourse and Navigation: An Analysis of Route Directions in the City of Venice. *Applied Cognitive Psychology*, 13:145–174, 1999.
5. P. G. Edmonds. Collaboration on Reference to Objects that are Not Mutually Known. In *15th International Conference on Computational Linguistics, COLING-94*, pages 1118–1122, Kyoto, 1994.

6. A. Frank. Pragmatic Information Content: How to Measure the Information in a Route Description. In M. Duckham, M. Goodchild, and M. Worboys, editors, *Foundations of Geographic Information Science*. Taylor & Francis, London and New York, 2003.
7. S. M. Freundschuh, D. M. Mark, S. Gopal, M. D. Gould, and H. Couclelis. Verbal directions for wayfinding: Implications for navigation and geographic information and analysis systems. In K. Brassel and H. Kishimoto, editors, *4th International Symposium on Spatial Data Handling*, pages 478–487, Zurich, 1990. Department of Geography, University of Zurich.
8. P. Grice. Logic and Conversation. In P. Cole and J. L. Morgan, editors, *Speech Acts*, pages 41–58. Academic Press, New York, 1975.
9. P. A. Heeman and G. Hirst. Collaborating on Referring Expressions. *Computational Linguistics*, 21(3):351–382, 1995.
10. S. Hirtle. Neighborhoods and Landmarks. In M. Duckham, M. Goodchild, and M. Worboys, editors, *Foundations of Geographic Information Science*, pages 191–203. Taylor & Francis, London and New York, 2003.
11. S. Hirtle and J. Jonides. Evidence of Hierarchies in Cognitive Maps. *Memory and Cognition*, 13:208–217, 1985.
12. R. J. Jarvella and W. Klein, editors. *Speech, Place, and Action*. John Wiley & Sons, Chichester, NY, 1982.
13. W. Klein. Wegauskünfte. *Zeitschrift für Literaturwissenschaft und Linguistik*, 33:9–57, 1979.
14. A. Klippel, H. Tappe, and C. Habel. Pictorial Representations of Routes: Chunking Route Segments During Comprehension. In C. Freksa, W. Brauer, C. Habel, and K. F. Wender, editors, *Spatial Cognition III — Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Learning*, volume 2685, pages 11–33. Springer-Verlag, Berlin, Lecture Notes in Artificial Intelligence edition, 2003.
15. K. L. Lovelace, M. Hegarty, and D. R. Montello. Elements of Good Route Directions in Familiar and Unfamiliar Environments. In *International Conference on Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science*, pages 65–82. Springer-Verlag, 1999.
16. K. Lynch. *The Image of the City*. The MIT Press, Cambridge, Massachusetts, USA, 1960.
17. E. L. Newman, J. B. Caplan, M. P. Kirschen, I. O. Korolev, R. Sekuler, and M. J. Kahana. Learning Your Way Around Town: Virtual Taxicab Drivers Reveal the Secrets of Navigational Learning. *Cognition*, 2005, in press.
18. I. Paraboni and K. van Deemeter. Generating Easy References: the Case of Document Deixis. In *Second International Conference on Natural Language Generation (INLG 2002)*, New York, USA, 2002.
19. J. Peterson and O. Chitil. Haskell.org – The Haskell Home Page. Available on: `http://www.haskell.org`, 2005. Visited on May, 15th 2005.
20. J. M. Plumert, C. Carswell, K. de Vet, and D. Ihrig. The Content and Organization of Communication about Object Locations. *Journal of Memory and Language*, 37:477–498, 1995.
21. J. M. Plumert, T. L. Spalding, and P. Nichols-Whitehead. Preferences for Ascending and Descending Hierarchical Organization in Spatial Communication. *Memory and Cognition*, 29(2):274–284, 2001.
22. C. E. Shannon and W. Weaver. *The Mathematical Theory of Communication*. The University of Illinois Press, Urbana, Illinois, 1949.
23. B. Shanon. Where Questions. In *17th Annual Meeting of the Association for Computational Linguistics*, University of California at San Diego, La Jolla, California, USA, 1979. ACL.

24. D. Sperber and D. Wilson. *Relevance*. Basil Blackwell Ltd, Oxford, UK, 1986.
25. S. Timpf, G. Volta, D. Pollock, and M. J. Egenhofer. A Conceptual Model of Wayfinding Using Multiple Levels of Abstraction. In A. Frank, I. Campari, and U. Formentini, editors, *Theory and methods of Spatio-Temporal Reasoning in Geographic Space*, volume 639 of *Lecture Notes in Computer Science*, pages 348–367, Pisa, Italy, 1992. Springer-Verlag.
26. B. Tversky. Cognitive Maps, Cognitive Collages, and Spatial Mental Models. In A. Frank and I. Campari, editors, *Spatial Information Theory: A Theoretical Basis for GIS, COSIT '93*, volume 716 of *Lecture Notes in Computer Science*, pages 14–24. Springer, Berlin, 1993.
27. E. Weissensteiner and S. Winter. Landmarks in the Communication of Route Directions. In M. J. Egenhofer, H. Miller, and C. Freksa, editors, *Geographic Information Science 2004*, volume 3234 of *Lecture Notes in Computer Science*, pages 313–326. Springer, Berlin, 2004.
28. J. M. Wiener and H. A. Mallot. 'Fine-to-Coarse' Route Planning and Navigation in Regionalized Environments. *Spatial Cognition and Computation*, 3(4):331–358, 2003.
29. M. Worboys. Communicating Geographic Information in Context. In M. Duckham, M. Goodchild, and M. Worboys, editors, *Foundations of Geographic Information Science*, pages 33–45. Taylor & Francis, London and New York, 2003.