Region-Based Model of Tour Planning Applied to Interactive Tour Generation

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Abstract. The paper addresses a tour planning problem, which encompasses weakly specified constraints such as different kinds of activities together with corresponding spatial assignments such as locations and regions. Alternative temporal orders of planed activities together with underspecified spatial assignments available at different levels of granularity lead to a high computational complexity of the given tour planning problem. The paper introduces the results of an exploratory tour planning study and a Region-based Direction Heuristic, derived from the acquired data. A gesture-based interaction model is proposed, which allows structuring the search space by a human user at a high level of abstraction for the subsequent generation of alternative solutions so that the proposed Region-based Direction Heuristic can be applied.

1 Introduction

Planning of different activities in an unfamiliar environment is a spatial task people are more or less often challenged with. Consider for example planning of a journey to a foreign city or a country. Before starting a journey, travelers have to agree on what they are going to do, i.e., different kinds of activities, together with where and when the activities will take place. Usually, the original considerations regarding the kind as well as the temporal order of activities together with corresponding locations are known only partially and at different levels of granularity: for example visiting of sightseeing attractions in a particular city, a part of a country, or swimming at a sea coast. Since most journeys are constrained in time, travelers have to consider how durations of alternative activities and time required for covering the distances between multiple destinations fit into the given temporal scope of a journey. Dealing with multiple spatio-temporal configurations und reasoning about various constraints is a cognitively demanding task [5].

On the one hand the illustrated problem domain encompasses partially specified activities together with spatial assignments, which are available at different levels of granularity or underspecified. And on the other hand, to compile a journey which our traveler enjoys means to find a solution out of different possible alternatives which fulfills such important criteria like the traveler's personal preferences, moods or even emotions. Since the personal criteria regarding the solution quality are difficult or

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even impossible to formalize, the given problem solving task cannot be totally outsourced to a computational constraint solver. To provide assistance with such type of Partially Unfomalized Constraint Satisfaction Problems (PUCP) we pursue in our recent work [11] a collaborative assistance approach, which requires the user's active participation in the given problem solving task [9].

Since the spatio-temporal planning task is now shared between an artificial assistance system and a user, the problem domain is separated into *hard constraints*, for example a temporal scope of a journey, specific locations, and types of activities, and s*oft constraints*, for example, personal preferences. An assistance system supplies a user with alternative solutions that fulfill the specified hard constraints. However, depending on the number of constraints left unspecified, we face the problem of high computational complexity as well as the problem of the obtained solution space becoming sufficiently large [12].

In our previous work we proposed a Region-based Representation Structure, which allows for specification of spatial and temporal constraints at different levels of granularity and generation of alternative solutions [10]. In [11] we proposed the region-based heuristics, which requires specific temporal order of activities and herewith are very well suited for modification of existing solutions at different levels of granularity. Yet, underspecified temporal order of activities drives the system to the limits of performance and hardly acceptable response times. The pioneering work of Krolak and colleagues demonstrated how the computational complexity of another spatial problem, namely the classical Traveling Salesman Problem, could be reduced using human-machine interaction. The search space has been structured by a human and herewith prepared for the subsequent computations performed by an artificial system [6].

Although a weakly specified tour planning problem is for the most of the people a cognitively demanding and time consuming task, they do manage to produce a single or a limited set of solutions for a given problem in a tolerable amount of time. To identify the underlying cognitive processes and problem solving strategies we conducted an exploratory study.

The paper introduces a gesture-based interaction model, which is based on the Region-based Model of Spatial Planning derived from the analysis of the acquired empirical data. The proposed interaction model provides users with operations that resemble the identified spatial problem solving strategies. The operations allow for pruning of significant parts of the search space and applying of the Region-based Direction Heuristic (RDH). The RDH doesn't require a predefined temporal order of activities and allows for efficient generation of alternative solutions. This paper represents a promising approach for solving computationally complex problems using human-machine interaction.

2 Tour Planning Problem

To plan a tour through a foreign country means to find a feasible temporal order of activities and corresponding routes under consideration of spatial and temporal constraints. An activity is defined by its type (*what)*, duration (*how long)* and a spatial

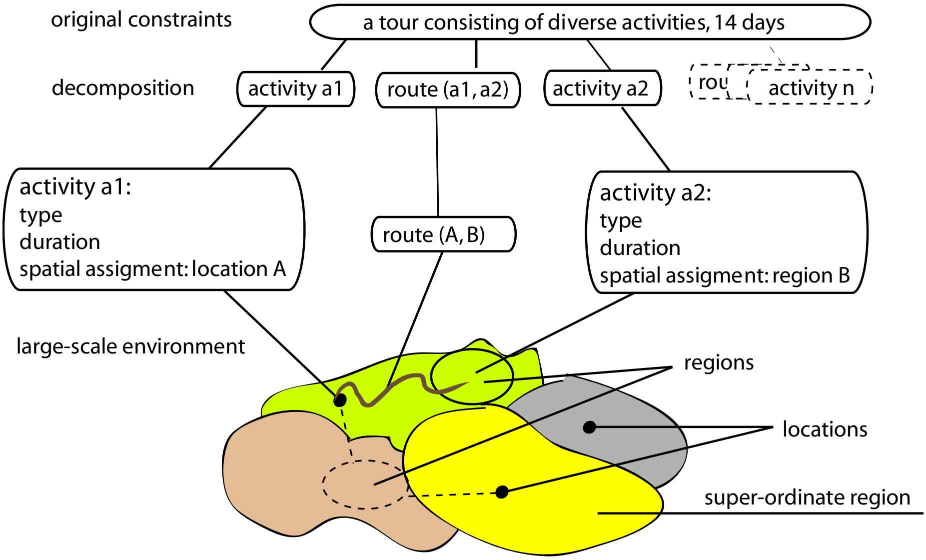

Fig. 1. Representation of the tour planning problem

assignment *(where)* ([2], [11]). Depending on the knowledge available at the beginning of the planning process, the initial set of activities and routes is underspecified (see Fig. 1).

Usually, at the beginning of the planning process spatial assignments are known only partially, i.e., defined at different levels of granularity: for example a particular location, a region, a part of the country, or left unspecified. An activity type can include a set of one of more possible options for activities, like swimming, or hiking, or also left unspecified.

Spatial constraints represent partially specified spatial assignments of the planned activities, and routes between them. We consider temporal constraints, which encompass an overall scope of a journey together with the condition that subsequent activities don't overlap with each other in time. An assistance system is responsible for instantiation of alternative spatial assignments as well as alternative temporal orders of activities. To solve the given tour planning problem means to find all possible spatio-temporal configurations consisting of different variations of activities, corresponding spatial assignments, and routes between them.

2.1 Region-Based Representation Structure

In our previous work [11] we introduced a collaborative spatial assistance system, which operates on a Region-based Representation Structure [10], and allows for interactive specification and relaxation of spatial constraints at different levels of granularity. The RRS is a graph-based knowledge representation structure, which encompasses a spatial hierarchy consisting of locations, activity regions and super-ordinate regions. Locations are associated with specific activity types and represent nodes of the graph, which are connected with each other via edges carrying distance costs. Activity regions contain locations, which share specific properties, like the user's requirements on activity types, which can be accomplished in that region. Super-ordinate regions divide a given environment into several parts. The structuring principles for super-ordinate regions are based on the empirical findings regarding mental processing of spatial information (e.g., [7], [13], and [4]). The RRS includes topological relations: how different locations are connected with each other. Containment relations between locations, activity regions, activity regions and super-ordinate regions are represented as *part-of* relations. Such spatial partnomies [1] allow for specifying spatial constraints and reasoning about spatial relations at different levels of granularity. The RRS also includes neighboring relations between corresponding super-ordinate regions.

In our exploratory study we aimed at identifying the cognitive mechanisms, such as structuring of the search space into regions, and strategies, which allow for solving the given planning task efficiently. The current contribution brings together both lines of research and demonstrates how reasoning and problem solving strategies utilized by humans can be mapped to operations on the Region-based Representation Structure, which is used for generation of the alternative solutions.

3 Region-Based Model of Tour Planning

Due to limitations of the cognitive capacity of the human mind people developed sophisticated strategies to deal with complex problems by dividing them into sub-problems [8] and solve them operating at different levels of abstraction [3].

The fine-to-coarse planning heuristic provides analysis and description of human strategies when performing a route-planning task, i.e., finding a path from one specific location to another specific location in a regionalized large-scale environment [14]. The heuristic operates on a hierarchically organized knowledge representation structure. The structure encompasses different abstraction levels, like places and regions. The route-planning procedure is executed simultaneously at different levels of granularity: information regarding close distances is activated at a fine level, i.e. places, whereas the information regarding far distances is represented at a coarse level, i.e., regions.

Based on the assumptions, that (1) mental knowledge is hierarchical and (2) regions help to solve spatial problems more efficiently, we conducted an exploratory study. The study aimed at asserting the role of regionalization in weakly specified tour planning problems.

3.1 Tour Planning Study

During the experiment subjects were asked to plan and provide a description of an individual journey to two imaginary friends, who intended to travel about the given environment. As an unfamiliar large-scale environment we chose Crete, which is a famous holiday island in Greece. The participants had to consider the following constraints: a journey had to start and end at the same location, cover 14 days, and encompass a variety of different activities. The participants were provided with a map, which was annotated with symbols representing different activity types. During the study, the participants had to accomplish the following tasks: 1) produce a feasible order of activities with concrete locations and routes between them, 2) draw the resulting route on the map, 3) describe the decisions they made by advising imaginary friends how to solve such tour planning problems. We analyzed the descriptions as well as the features of the produced tours, such as the shape resulting from selected routes. The results allow us to derive the following assumptions regarding the underlying problem solving strategies.

3.2 Regionalization

Humans solve such kind of planning problems using different levels of abstraction [3]. The analysis of the descriptions revealed, that the participants divided the given environment into several super-ordinate regions according to the salient structural features of the environment. The salient features are topographical properties such as landscapes, sea coast, and major cities. Herewith, the super-ordinate regions build the highest level of abstraction. The subjects identified attractions situated in super-ordinate regions and made a decision, which super-ordinate regions were worth visiting.

3.3 Region-Based Direction Strategy

Since mental regions may have only vague boundaries, Fig. 2 provides a schematic illustration of a separation of a given environment into several regions according to its salient structural features, e.g., major cities and landscapes. Additionally, the structuring principles based on cardinal directions, reported by [7], were applied (Fig. 3).

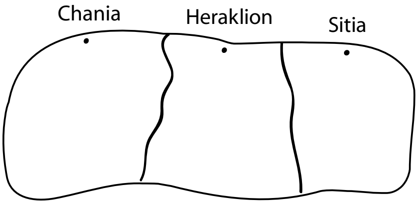

Fig. 2. Division in 3 parts

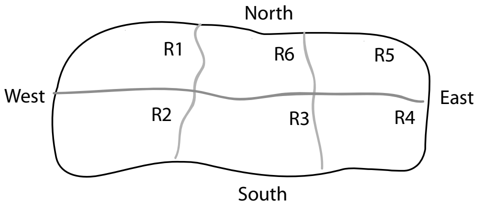

Fig. 3. Regions resulting from cardinal directions

Such regions build the highest level of abstraction. After that the subjects searched for the attractions situated in the high-level regions, and if required cluster the attractions into smaller regions, e.g., sea coast, which share specific properties, such as vicinity of towns or specific landscapes.

While selecting the appropriate locations, the subjects put high-level regions in a particular order (see Fig. 4): e.g., getting from the northern part of the island to the south coast. Due to the cognitive model of planning [3] a human is capable of changing his plan at different levels of abstraction at any point at time. That means that the order of current and subsequent high-level regions influence the planning process at a finer level of granularity (see Fig. 5), and the other way round, decisions made on the finer level impact the order of the high-level regions.

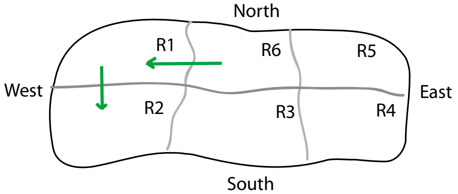

Fig. 4. High-level order relations

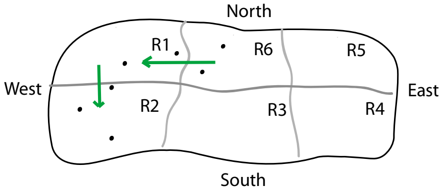

Fig. 5. Selection of locations

3.4 Region-Based Direction Heuristic

The region-based direction heuristic utilizes the direction relations between the neighboring super-ordinate regions, e.g., super-ordinate region R1 in the west of super-ordinate region R6 (see Fig. 4). To implement the RDH we extended the neighboring relations between the super-ordinate regions of the Region-based Representation Structure with corresponding cardinal directions. The edges between different locations, which represent nodes of the hierarchical region-based graph, have to be also supplemented with direction information between the nodes.

Now, the super-ordinate regions are related to each other by neighboring relations, e.g., R6 is neighbor of R1, R3, R5 and cardinal directions between the neighboring regions: West(R6, R1), South(R6, R3), East(R6, R5). The generation of alternative tours is implemented as a depth-first search algorithm, which considers the direction information between subsequent super-ordinate regions when selecting appropriate nodes, e.g., R6, R1, R2, R3, R6 (see Fig 6., Fig. 7).

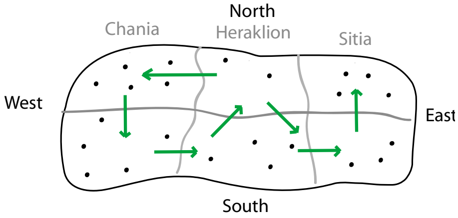

Fig. 6. High-level order of regions

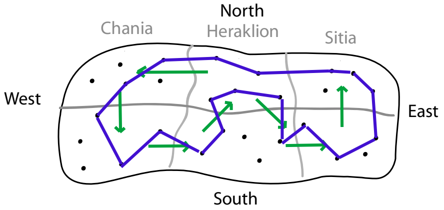

Fig. 7. Tour resulting from the high-level order of the super-ordinate regions

To preserve the high-level course of a tour, which is defined by the order of the super-ordinate regions each current node *node n* and a subsequent *node n+1* should satisfy the following criteria:

1. *Node n* and *node n+1* belong to the same super-ordinate region, or *node n+1* belongs to the next super-ordinate region from the ordered set of super-ordinate regions.
2. Each node is visited only once.

3. The selection of the subsequent *node n+1* depends on the direction relation between the subsequent super-ordinate regions, i.e., the coarse direction.
4. First, the nodes are selected, which presume the direction of the subsequent super-ordinate regions.
5. If no nodes can be found which correspond to the direction relation that holds between two subsequent super-ordinate regions, the algorithm starts with instantiation of slight deviations from the course of the journey.
6. The opposite direction to the direction between two subsequent super-ordinate regions is tried as the last opportunity.
7. Nodes, which are situated in the last super-ordinate region, presume the direction relation between the last pair of super-ordinate regions.

The proposed search heuristics allow the efficient generation of trips. Nevertheless, an assistance system needs the user's input to start with the generation procedure. In the next section we introduce an interaction model, which arose from the described exploratory study. The interaction model resembles the described problem solving steps and allows for utilizing of the proposed heuristics.

4 Interactive Tour Planning

The assistance system operates on a touch screen device equipped with a pen-like pointing device. Such pointing devices have also additional buttons, to provide the functionality of the right, middle and left buttons of a conventional computer mouse. The following figures demonstrate the selection of spatial assignments at different levels of granularity. The constraints are represented as a list of activities, which are defined by an activity type, duration, and a spatial assignment.

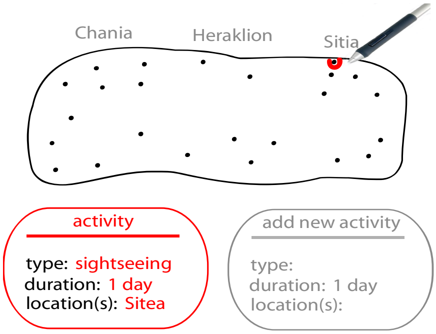

Fig. 8. Selection of a fixed location

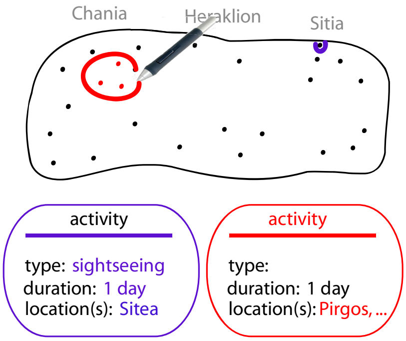

Fig. 9. Selection of a user-specific region

Figure 8 illustrates a definition of a fixed location with a specific activity type. Figure 9 demonstrates a selection of a user-specific region, which is considered as a set of optional locations for a specified activity.

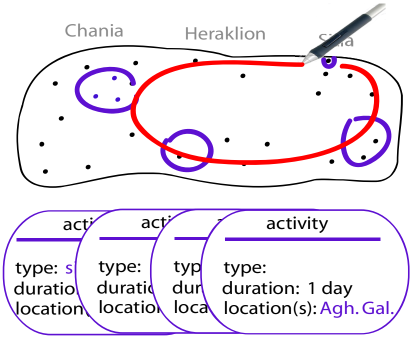

Fig. 10. Setting up the high-level order of super-ordinate regions

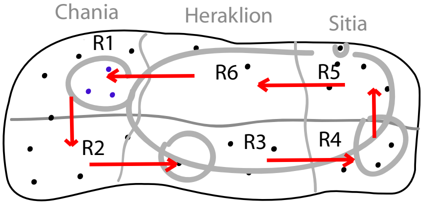

Fig. 11. Internal representation of the user-defined order of the super-ordinate regions

Figure 10 illustrates the definition of a high-level order of the super-ordinate regions. Figure 11 shows the corresponding internal representation of the assistance system: R5, R6, R1, R2, R3, R4, R5, which are used for the generation of alternative solutions.

5 Conclusion

In the scope of the paper we demonstrated how human-machine interaction can be employed for solving computationally complex problems. In our pervious work we proposed the cognitively motivated Region-based Representation Structure, which resembles the hierarchical mental knowledge representation. The current contribution introduced a gesture-based interaction model, which operates on the RRS and allows not only for definition of constraints at different levels of granularity, but also for preparation of the search space by a human user at a high-level of abstraction for the subsequent constraint solving procedure.

Due to non deterministic human planning behavior, the specific order of high-level regions can be changed during the process of planning. The RRS and the demonstrated interaction model allows for generation of sub-tours at any point in time. Taking into consideration the direction relations between the neighboring high level regions the Region-based Direction Heuristic allows for operating on different levels of granularity and an efficient integration of partial sub-plans into a consistent overall solution.

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References

1. Bittner, T., Stell, J.G.: Vagueness and Rough Location. Geoinformatica 6, 99–121 (2002)
2. Brown, B.: Working on problems of tourist. Annals of Tourism Research 34(2), 364–368 (2007)
3. Hayes-Roth, B., Hayes-Roth, F.: A Cognitive Model of Planning. Cognitive Science 3, 275–310 (1979)
4. Hirtle, S.C.: The cognitive atlas: using GIS as a metaphor for memory. In: Egenhofer, M., Golledge, R. (eds.) Spatial and temporal reasoning in geographic information systems, pp. 267–276. Oxford University Press, Oxford (1998)
5. Johnson-Laird, P.N.: Mental models. Harvard University Press, Cambridge, MA (1983)
6. Krolak, P., Felts, W., Marble, G.: A Man-Machine Approach Toward Solving the Traveling Salesman Problem. Communications of the ACM 14(5), 327–334 (1971)
7. Lyi, Y., Wang, X., Jin, X., Wu, L.: On Internal Cardinal Direction Relations. In: Cohn, A.G., Mark, D.M. (eds.) COSIT 2005. LNCS, vol. 3693, pp. 283–299. Springer, Heidelberg (2005)
8. Newell, A., Simon, H.A.: Human problem solving. Prentice Hall, Englewood Cliffs, NJ (1972)
9. Schlieder, C., Hagen, C.: Interactive layout generation with a diagrammatic constraint language. In: Habel, C., Brauer, W., Freksa, C., Wender, K.F. (eds.) Spatial Cognition II. LNCS (LNAI), vol. 1849, pp. 198–211. Springer, Heidelberg (2000)
10. Seifert, I., Barkowsky T., Freksa, C.: Region-Based Representation for Assistance with Spatio-Temporal Planning in Unfamiliar Environments. In: Gartner, G., Cartwright, W., Peterson, M.,P.: Location Based Services and TeleCartography, Lecture Notes in Geoinformation and Cartography, pp. 179–191, Springer, Heidelberg (2007)
11. Seifert, I.: Collaborative Assistance with Spatio-Temporal Planning Problems. In: Spatial Cognition 2006. LNCS, Springer, Heidelberg (to appear)
12. Stamatopoulos, P., Karali, I., Halatsis, C.: PETINA - Tour Generation Using the ElipSys Inference System. In: Proceedings of the ACM Symposium on Applied Computing SAC '92, Kansas City, pp. 320–327 (1992)
13. Tversky, B.: Cognitive maps, cognitive collages, and spatial mental models. In: Campari, I., Frank, A.U. (eds.) COSIT 1993. LNCS, vol. 716, pp. 14–24. Springer, Heidelberg (1993)
14. Wiener, J.M.: PhD Thesis, University of Tübingen, Germany: Places and Regions in Perception, Route Planning, and Spatial Memory (2004)