Towards cognitively adequate interaction for mental model-based spatio-temporal assistance

Inessa Seifert

SFB TR 8/ Spatial Cognition,
University of Bremen, Germany
seifert@informatik.uni-bremen.de

Abstract

This paper presents an approach for interaction between a human user and a mental model-based spatio-temporal assistance system based on the definitions for conceptual and inferential cognitive adequacy (cf. Knauff et. al., 1995). The paper introduces work in progress that covers ideas towards a visual interaction language that provides cognitively adequate knowledge representation and interaction during cognitively demanding spatio-temporal tasks. A trade fair example described in the paper provides an application domain for spatio-temporal problem solving and reasoning tasks. Ideas for adequate knowledge representation, interaction, and reasoning with external media are discussed.

Introduction

This paper introduces ideas towards cognitively adequate interaction with an assistance system during cognitively demanding spatio-temporal tasks. At the beginning, it is necessary to define, what cognitively adequate interaction means. There are different agreements on what cognitive adequacy is. In a strong sense, it means that a system should operate on a model of human cognition; in a weak sense, it should be user-friendly and fulfill ergonomic requirements (cf. Strube 1992). In the scope of this paper I will refer to the definitions, provided in (Knauff et. al., 1995), where it has been distinguished between conceptual cognitive adequacy and inferential cognitive adequacy. From that follows that cognitively adequate assistance implies on the one hand knowledge representation resembling human conceptual knowledge and on the other hand interaction with an assistance system that resembles human reasoning processes about spatio-temporal relations. This paper introduces my work in progress and focuses on analysis of human problem solving and reasoning strategies using external media and diagrams in spatio-temporal problem domain.

The problem domain I am analyzing has a static spatial structure and a variety of temporal and spatial constraints. The spatio-temporal dynamics is provided by a set of constraints which may contradict with each other, be partially ordered or interdependent. A yearly trade fair serves as an example of such problem type, where temporal constraints and time frames are given as: opening hours of the trade fair or particular pavilions, special exhibitions or demonstrations of new products and fixed appointments for meetings in particular locations. Trade fair visitors should be assisted at cognitive demanding tasks like: making up appointments with more or less important people: e.g. customers, colleagues, friends; selecting more or less interesting booths; and rescheduling of appointments under time pressure if they are delayed, added or cancelled. All of the summarized tasks contribute to a cognitively demanding spatio-temporal task that needs to be assisted.

Collaborative assistance

Schlieder proposed in his works the term of hybrid or asymmetric assistance which operates on collaboration of a computational constraint solver and a human (cf. Schlieder & Vögele, 2002). Modern constraint satisfaction and propagation algorithms are powerful enough to provide solutions in a relative short time. However not all of the constraints can be specified formally and some of them, like personal preferences are hard to define or even to formalize (cf. Schlieder & Hagen, 2000). The underspecified spatio-temporal constraints lead to large solution spaces consisting of many alternatives. The mental processing of the variety of produced alternatives is a cognitive demanding task (cf. Knauff et. al., 2002). However, a way to attack this problem was found. Psychological experiments with humans have shown that the subjects have chosen the same mental models (in the sense of Johnson-Laird, 1983) from the large solution space. The mental models chosen by the participants of the experiment were called the preferred mental models (Knauff et. al., 1995). Nevertheless there are more steps required towards cognitively adequate collaboration between a human and an assistance system.

Mobile multi-user and multi-device assistance system

The concept of a mental model-based assistance system in a ubiquitous computing environment was proposed in (Seifert et. al., 2004). In the scope of this paper I will provide a short overview of the concept. The proposed assistance system operates on mobile communication devices, e.g., PDAs and stationary table PCs or smart boards. The devices have different visual capabilities (e.g., display properties), support user mobility and can communicate with other devices over heterogeneous networks. The basic application scenario can be described as follows:

Our trade fair visitor arranges necessary appointments at his office using a smart board, which provides information about the static structure of a trade fair. After our visitor has selected booths he/she is interested in and set priorities and dependencies so that different alternatives can be generated and finally one (or some) of them can be chosen. A preliminary schedule is finished and can be stored on a mobile device. However this is only part of the spatio-temporal problem. The proposed system assists our user in a highly dynamic trade fair environment at setting new priorities, rescheduling of appointments and visualizing of alternatives in order to support our user in decision making processes.

There exists a huge amount of sophisticated communication devices. Although most of them have enormous computational capacities compared to humans, they still differ from us in interaction capabilities and available communication channels: e.g., touch screens, keyboards, displays and microphones. Due to interaction limitations of supporting devices we have to find a compromise between a technical assistance system and a human for successful cognitively adequate collaboration. In the subsequent sections I will introduce some ideas for exploration studies towards interaction language between a user and an assistance system.

Towards cognitively adequate spatio-temporal knowledge representation

One of the requirements on cognitively adequate assistance is a knowledge representation, which resembles human conceptual knowledge about space. Much has been written on internal mental spatial knowledge representation, beginning with metaphors like cognitive maps, cognitive collages, atlases, or spatial mental models, depending on the field of research and the focus taken (e.g. Tversky, 1993, Hirtle, 1998). Cognitive maps are of a great help at way finding tasks, they can barely provide information about destinations and estimated durations. Series of psychological experiments (cf. Klippel et. al., 2004) have shown people tend to misinterpret distances between connected and as well as not connected cities due to perceptually induced distortions in cognitive maps. The aim of my exploration studies is to find such phenomena, where an assistance system could provide the "perfect" knowledge about spatial constraints combining it with cognitively adequate representation, e.g., cognitive maps.

Many research activities are concerned with spatial knowledge representation in the field of robotics, e.g., route graphs (c.f. Werner et. al., 2000) or in the field of way finding in public transport (cf. Rüetschi & Timpf, 2004). The truth lies somewhere between perfectly computed solutions of underspecified spatio-temporal constraints and their visual representation.

However, not only methods for cognitively adequate knowledge representation must be considered, but also capabilities of the assisting devices play an important part in the interaction. From that point of view the following research questions arise:

- Spatial and temporal constraints can be visualized in a textual form, a diagram or both (i.e., enriched representation). What are the preferred representations due to visualization capabilities of digital media and how do these capabilities, e.g., display size, available colors affect the representation?
- What are preferred media and information artifacts (e.g., fair plan with extra list of appointments or just a fair plan augmented with appointments)?
- Are there differences in choosing preferred media if one person is involved in planning process, or the planning task is shared between more than one people? How is information about schedules and plans exchanged: over texts, lists or diagrams?

Dealing with underspecified constraints many alternative solutions that fulfill given spatio-temporal premises are possible. The automatic generation of preferred models is still a matter of further research. One of the methods is an empirical study about preferred mental models and derivation of specific rules in the given problem and application domain.

However this paper focuses on methods and questions for the definition of a visual interaction language between an assistance system and a human.

Visual interaction language

First of all geometric primitives have to be identified in order to define a set of elements, which can be assembled to a diagrammatic, enriched representation. Although there exist many solutions visualizing only temporal or only spatial constraints (e.g. Hoebel et. al., 1998, Blaser et. al., 2000), there is still a question how partial orders and interdependencies, where both kinds of constraints must be taken into consideration, can be visualized properly. Tversky's work on pictorial and verbal tools for conveying routes (cf. Tversky & Lee, 1999) has inspired me to employ her methods (e.g. protocol analyses, thinking aloud) to define an interaction vocabulary for spatio-temporal knowledge representation.

Towards cognitively adequate interaction

There are different strategies to create a schedule for a trade fair visit. One of the strategies is to arrange all important appointments and then to analyze, what are interesting booths and after that create a preliminary schedule. Another one is to select interesting booths first, compute preliminary alternative routes of visit and after that arrange important appointments proposing the computed durations and points in time.
My scientific questions for the exploration studies are:

- What are the strategies people are most familiar with?
- Are there differences between experts, who planed visits many times before and novices?
- Do other strategies exist?
- How large has a spatial environment to be and how many temporal and spatial constraints are needed, so that some kind of strategy has to be applied?
- And the most important question: In which particular planning tasks is assistance needed?

As I mentioned above, our visitor should be assisted not only in an early planning stage, but also during his/her visit to the trade fair. Further question for the exploration study are:

- What kind of cognitive operations are needed to reschedule one or more appointments? How many cognitive operations are needed to understand the changes for example in location? In time? Both?
- What is the preferred media (and channel) to communicate the changes in the environment? How are they visualized: text, picture or enriched representation? Does it depend on an amount of communication partners?
- How many changes in a schedule have to be considered in order to switch from one medium to another with larger display size (e.g. from PDA to smart board)?
- What are the main features of information artefacts which capture user's focus of attention? How does attention shifting take place? (cf. Suwa & Tversky, 1997).

The amount and kind of information provided by the media and informational artifacts plays an important part during the collaboration process. There are different strategies to deal with different requirements, e.g., in the field of architecture by focusing on specific aspects of a problem domain (cf. Bertel et. al., 2004). Through the proposed exploration study we can find rules how the given application domain can be separated in different aspects according to the spatio-temporal context of the user.
After defining the geometric primitives and annotations needed to express interdependencies and partial orders, a study is needed, how this information can be understood by the users. The work of (Seligmann & Feiner, 1991) introduces an approach for automatic generation of 3D illustrations for usage of electronic mass media by formalizing a communication intent which consists of many specific communication goals. It would be interesting to apply a similar method and verify whether the communication intents and the diagrammatic representation based on elaborated geometric primitives are understood by the assisted users in an adequate way.

Outlook and future work

In the scope of the planned exploration studies paper based mockups that vary in size and emulate different digital media will be used. For example different device properties, like colored displays can be simulated with colored pencils. For the analyses of interaction with different media and information artifacts such methods like: speaking aloud, audio recording and video confrontation will be used. Subsequently the protocols of the proposed studies will be analyzed.
This paper introduces my work in progress and therefore provides more questions than answers. Another important aspect is that I'm not a psychologist and the proposed exploration (or usability) studies are not indented to be valid from a psychological point of view. However the results of these studies could provide interesting research questions that would require deeper psychological analyses.

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