Year: 2011

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Originally published at:
Crease, P E; Reichenbacher, T (2011). Designing usable cartographic representations of geographic relevance for LBS users. In: 25th International Cartographic Conference, Paris, FR, 3 July 2011 - 8 July 2011, CO-073.

Adapting Cartographic Representations to Improve the Information Seeking of LBS Users

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1. Introduction

Recent efforts to enhance the mobile information seeking of LBS users have focused on the discovery of more thorough methods of relevance assessment. This focus is perhaps best embodied within the concept of Geographic Relevance (GR) first proposed by (Raper 2007) and extended by (Reichenbacher 2009; Reichenbacher et al. 2009). However, assessing the relevance of information is only a first step. To fully realise the potential of such work it is also crucial to discover efficient and meaningful ways to communicate this assessed relevance to the information seeker. As GR is an inherently spatial concept, it is foreseen that cartographic representations will play a central role in the communication process. This paper aims to define how these cartographic representations can be designed to enhance and support the cognitive processes of mobile users searching for relevant places through analysis of the links between the user's cognitive processes and the cartographic representation. First, the background of GR is discussed and the links between cognition and cartographic representations are explored. We then highlight current problems of a working location-based service (LBS). Approaches to solve these problems are then discussed and prototypically demonstrated.

2. Background

A powerful means to aid mobile information seeking is found through the ability to assess what is relevant. Extending the concepts found within information seeking to the mobile setting has resulted in the paradigm of Geographic Relevance. Geographic Relevance (GR) aims to improve on the current relevance assessments employed by commercial mobile search systems which remain relatively simple (Raper et al. 2007). The simplicity results from a very basic appreciation of the user's context utilized by these systems to derive the information needs (Ehlen et al. 2009). A second criticism is that currently relevance is often treated as a binary measure which is visually represented through the application of filters that remove any 'irrelevant' spatial information (Mountain and MacFarlane 2007). This introduces limitations to the usefulness of the information returned and its ability to support good decision-making. Moreover, does the binary approach not mirror how people conceptualise relevance. Empirical studies suggest that relevance is conceptualised as several grades or categories ranging from irrelevant to highly relevant (Tang et al. 1999; Cosijn and Ingwersen 2000). GR aims to tackle the above limitations through more comprehensive and finer grained context modelling, nonbinary relevance measures and more sophisticated handling of space (Reichenbacher et al. 2009) so that an information seeker's questions concerning the locations of entities that are relevant (where), the types of entity that are relevant (what) and the times at which an entity will be relevant (when) are more comprehensively answered.

To make full use of GR the task of the visual representation is to communicate these 'answers' to the information seeker and make the relevance of the information for a specific usage context explicit. Past methods have communicated this answer by simply mapping the relevance values to visual variables symbolising points of interest (Reichenbacher 2007). However, it is argued here that this kind of relevance visualisation is probably not sufficient and comprehensible for the user and that further properties of the visual representation will also need to be adapted to enrich the communication process and support the information seeking of the user. The main goal of this paper is to specifically address how these properties of the representation should be formed to successfully and efficiently communicate which geographic objects are relevant to a user by applying the concept of External Cognition.

3. How Representations Extend Cognition

Human cognition has long been understood as a limited resource that is easily overloaded, resulting in frequent sub-optimal behaviours, e.g. (Simon 1955; Kleinmuntz and Schkade 1993). However, these limitations can partly be overcome through the development and use of external tools that can enhance our own cognitive abilities. Developing such tools has been highlighted as something unique to humans (Tversky 2005). Representational systems are an excellent example of a cognitive tool that can externalise and enhance our cognition. Cartographic representations are a special instance of a tool that serves exactly this function. They extend our cognition of space by increasing our ability to store, perceive and process spatial information (Wood 2001). Norman (1991) defines three main components that characterise any representational system as:

- The represented world
- The representing world as a set of symbols
- An interpreter (which includes procedures for operating upon the representation)

Cognitive scientists and cartographers have more recently become aware that a systematic analysis of the link between the second and third component is important if we are to discover why and how some representations enhance our problem solving abilities (Norman 1986; Zhang 1997; MacEachren 2001). This way of thinking, in the context of graphical representation, has been termed 'External Cognition' by Scaife and Rogers (Scaife and Rogers 1996) and can certainly be applied to pictorial, map-like representations of space. External cognition utilises a framework consisting of three main characteristics of representations that can be used to examine the usability of any given representation:

- Computational Offloading – this characteristic describes how different representations of the same problem can influence, positively or negatively, the mental processing required to interpret an external representation and generate a solution. High computational offload means that many of the cognitive tasks are transferred onto the representation, meaning lower cognitive loads for the interpreter. This idea is in some way analogous to the idea of 'Knowledge in the World' versus 'Knowledge in the Head' proposed by Norman (Norman 1993; 2002). An example would be the difference between the multiplications of two large numbers with the use of pen and paper versus with the use of a calculator. The calculator removes the need to perform numerous multiplications in the head. For spatial representations differences in offloading exist between pictorial representations versus linguistic representations of space. Pictorial representations hold implicit information that can communicate complex spatial layouts, share spatial constraints with the represented world and can be visually processed in parallel (Tversky and Lee 1999; Peuquet 2002; Habel 2003). Deriving these characteristics of spaces from verbal descriptions requires more cognitive processing, which can make them unsuitable or at least less efficient for certain tasks.

- Re-Representation – Utilising structures that are familiar can facilitate the deciphering or manipulating of a graphical representation. An example can be found in the study of (Zhang and Norman 1994) and their use of the Tower of Hanoi problem which demonstrates how problems with the same abstract structure but represented differently alter the efficiency and accuracy of subjects to solve problems.

- Graphical Constraining – Representations can lead, if poorly designed, to an incorrect inference based on misinterpretation. Often it is possible to design a representation in such a way that any expected incorrect inferences cannot be possible drawn from it. An example of these ambiguities in maps could be found in confusion over figure-ground relationships that can be removed with the proper application of visual emphasis techniques (Tomaszewski 2007).

Figure 1 shows how these three elements fit together in a task-oriented model of tasks and their resulting actions. It is assumed that cognitive faculties can be aided by external representations to solve a task (Zhang 1997; Barkowsky 2002). For example the use of a simple paper map would naturally involve the user directing their visual attention towards the map whilst also needing to apply higher level forms of cognition such as using conscious thought to decide on future actions. External Cognition represents a relationship between the representation and cognition; if the representation mediates a task by supporting the cognitive processes necessary to solve a task then this relationship is a positive one. Human cognitive resources can be categorised into 13 cognitive faculties (CF). For a review of these 13 CF and the roles they play see (Oulasvirta et al. 2005). For simplification these have been simplified into 8 categories that are perceived as being relevant to this study. Types of visual representations that support external cognition can been divided into 11 different categories (Lohse et al. 1994). Of these 11 categories maps, networks (e.g. the London Underground Map) and cartograms play perhaps the most influential role when the task being solved relates to actions in geographic space.

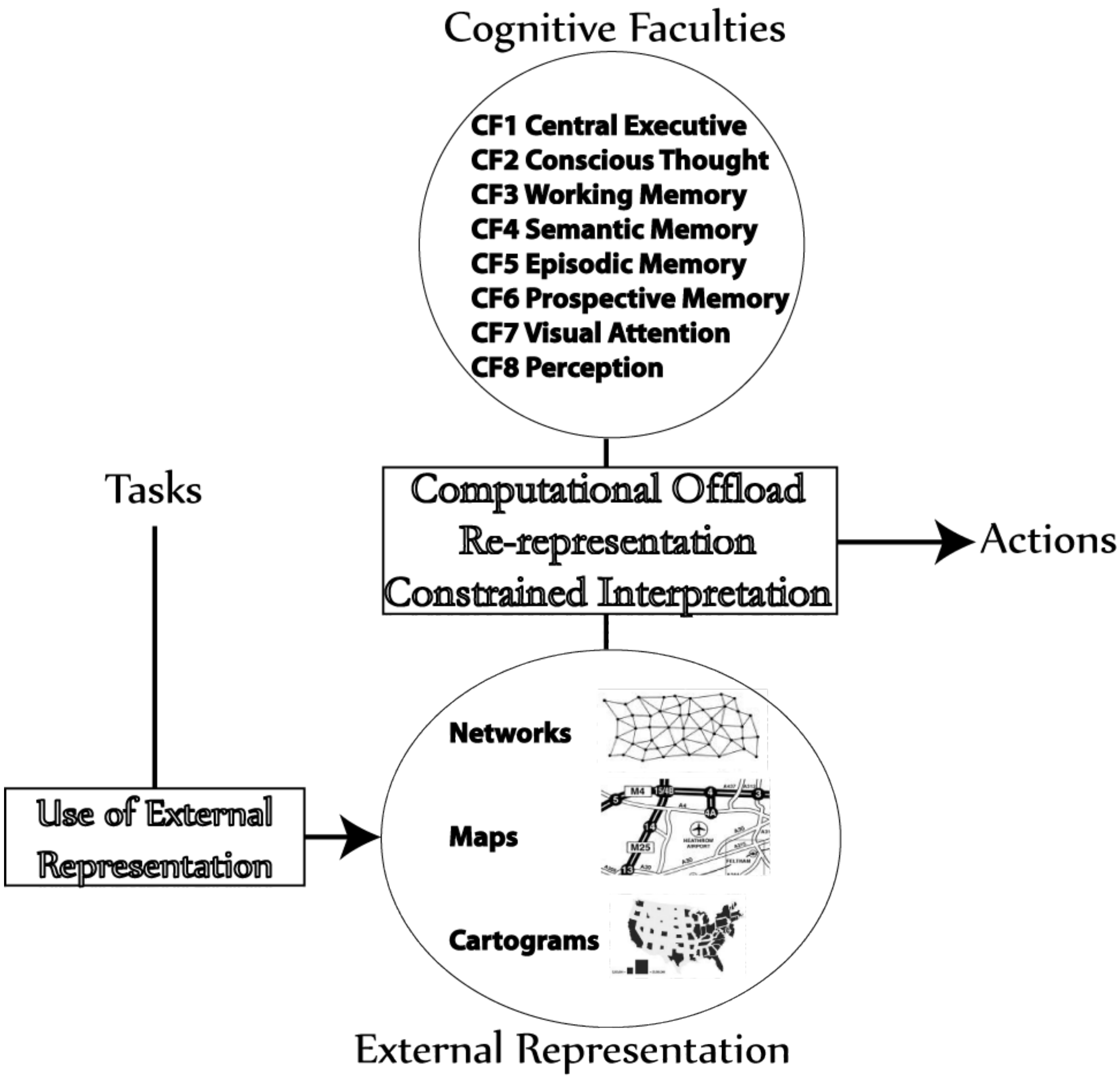

Figure 1 - Cognitive relationship between tasks, cognition, representation and Actions. Based on Oulasvirta (2004) and Lohse et al. (1994).

Importantly, these three types of external visual representations of space are strengthened by their ability to abstract. This allows them, for many use cases, to be efficiently employed in the solution of problems by focusing on fundamental aspects of the represented phenomena while neglecting unnecessary details. Similarly, the explicitness of information in map representations has the potential to ease the cognitive processing and make it more efficient. The explicitness, the abstraction and the analogue character of map representations also may release capacities of visual attention, memory and conscious thought (highlighted in black in Figure 1). They support human cognitive processes by acting as a means to store information about our environment, acting as an external form of memory (CF3, CF4, CF5 & CF6). These representations also are simplifications of the real world and contain, when well designed, only the relevant features that directly relate to the tasks of the map reader thereby directing our attention effectively and supporting our visual cognition (CF1, CF7 & CF8). Most crucially they allow us to perceive geographic information over large geographic extents that humans could not otherwise directly perceive and therefore can positively influence our reasoning and decision making (CF2). This reduces cognitive workload for user interaction and allows cognitive resources to be better employed for higher-level processes, such as planning, decision-making, or problem solving, e.g. (Tversky 2005; Swienty et al. 2008).

4. How Representations Hinder Cognition

As well as offering computational offload, external visual representations may cause computational or information overload, e.g. due to too much information (Navarro-Prieto et al. 1999). More perceptual information may provide computational offloading in terms of explicitness, but too much information may result in complexity, creating difficulty in focus of attention (Price 2002). Apart from the number of represented phenomena this complexity may be caused by the inherent complexity of the phenomena, their relationships, or the visual detail. Castner and Eastman (1985) distinguish between visual, i.e. the complexity of stimuli, and functional or intellectual complexity.

As discussed in (Reichenbacher 2009), visual complexity is influenced through structural and syntactic properties of map signs, i.e. absolute number of map elements, their relative density, their level of detail (e.g. form complexity or number of colour values or hues), the visual structure (number of discrete, disjoint objects versus connected or associated objects), as well as the presence and number of labels. Intellectual or functional complexity refers to the intrinsic complexity of the phenomena to be represented and their relationship. This complexity manifests itself during the cognitive processing of the map, i.e. the understanding of the map within a specific context (Fairbirn 2006). As a third type of complexity one might add the semantic complexity, i.e. the number of different types or categories in a representation (Reichenbacher 2009). The semantic complexity of a representation rises with the number of distinct types or categories represented. Yet, representing a large number of objects of the same category yields a representation of high visual, but low semantic complexity.

Means to design map representations that support cognitive processes without overloading the map representation are shown in Figure 2.

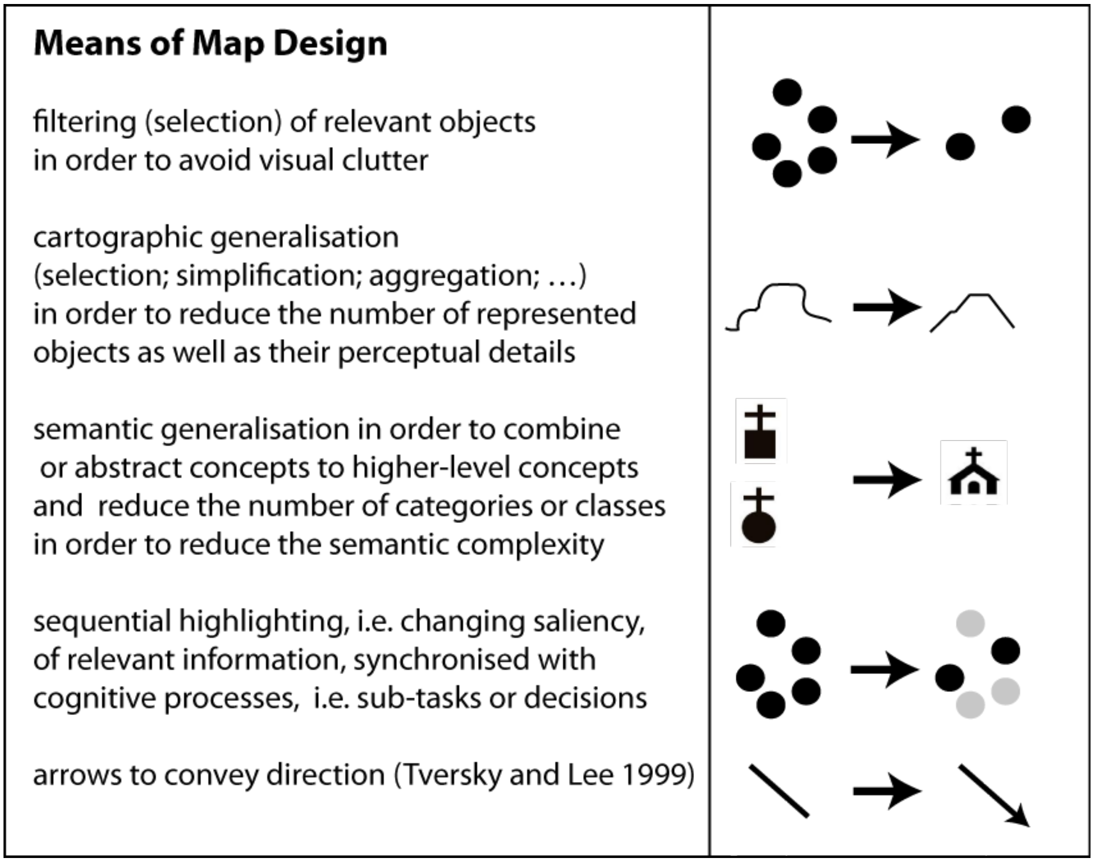

Figure 2 – Means of map design to support cognitive processes

5. An exemplary use case of a relevance representation in LBS

This section will be split into several subsections. First we will describe a short scenario to be analysed and then analyse the tasks associated with this scenario. Next the cognitive faculties employed when using a typical LBS map representation to solve the previously described tasks will be listed. This step will again be repeated but instead with a map representation specifically designed to support external cognition within the given context and tasks derived from the scenario.

5.1. Scenario

To illustrate the adaptation of a map representation for supporting and enhancing an LBS user's cognitive processing of geographic information we will provide a short scenario acting as a representative use case: *A user situated at location A in a city has a meeting scheduled at location B in 30 minutes. Before the meeting the user needs to find a cash point. The user possesses a state-of-the-art Smartphone including a GPS chip*.

Analysing this simple scenario, we can identify the user's goal as finding an ATM close enough to the route between location A and location B in order to be in time for the meeting at location

B. This suggests that more relevant ATMs will be situated in the general direction of travel between locations A and B and they will be accessible within the situation's time frame. These characteristics of ATMs can be linked directly to the relevance criteria of directionality and spatio-temporal accessibility, as described by DeSabbata (De Sabbata 2010). Developing representations that can help users to find ATMs that fulfil these relevance criteria are likely to aid information seeking activities.

5.2. **Analysis of Task**

Next, we will analyse the tasks involved in solving the problem of getting from A to B and finding an ATM in-between (Figure 2). The tasks can be broadly categorised into analysis, decision and action stages. We choose to focus upon the analysis stages since these relate most closely to the information needs of a mobile individual, which a representation should seek to support. The last three steps involve the actual decision and actions taken and lie outside the scope of this paper. The approach will consist of defining how a typical LBS would act as source of external cognition to a user involved in this scenario and showing how this external cognition could be enhanced through a map adapted to better communicate the spatial qualities (directionality, spatio-temporal accessibility) that affect the relevance of each ATM. The assumption in both cases is the availability of a map representation depicting the city in our scenario.

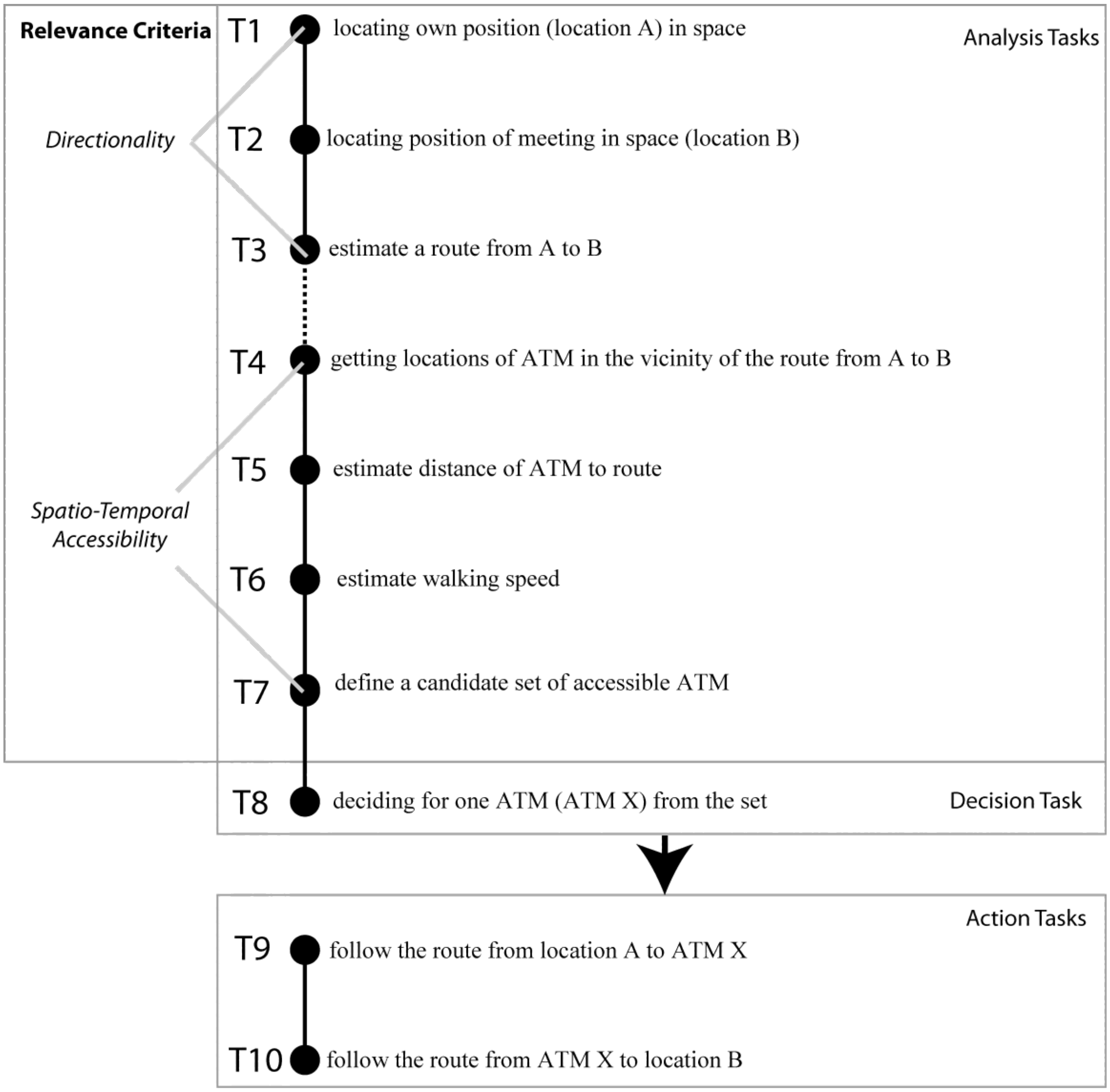

Figure 3 - Analysis of cognitive tasks (T1 to T7) and the resulting actions (T8 – T10)

5.3. Support by State-of-the-Art LBS

It is assumed that a typical LBS map representation offers the following functionality shown below:

- ability to search by zip code
- ability to use the GPS feature of the Smartphone to search based on the current location
- distance information
- direct link to Google maps for map and directions
- automatic panning of the map, centring to the user's location and displaying it

- capability to email ATM location information

The first thing the user in the scenario will do is to query the LBS for ATMs based on the current location. The LBS will then return a map representation showing the locations of ATMs around the current location of the user (Figure 3).

Figure 4 – Map Representation of a typical LBS Service for the given scenario (Source: http://www.google.co.uk/mobile/maps/#p=default; ©2010 Google)

This representation will result in cognitive offloading for the tasks T1 and T4 (Figure 4); the first task (T1) is supported by the displaying of the user location. This means that several cognitive faculties are released. The user does not need to switch attention between screen and environment (CF 1) whilst still holding the characteristics of the environment in their memory (CF 3) and needing to link the environment and map representation together through conscious action (CF 2) or possibly by applying factual past knowledge about the location of possible landmarks in view (CF4) (Kray 2003). The fourth task (T4) is also partially supported as the user is provided with locations of ATMs and thus he or she is not required to remember them (CF4). All other steps must be mentally estimated in order to arrive at a decision. Possible incorrect inferences could be choosing ATMs that are not accessible within the time limit of 30 minutes which could be caused by estimating an incorrect route or location of the destination.

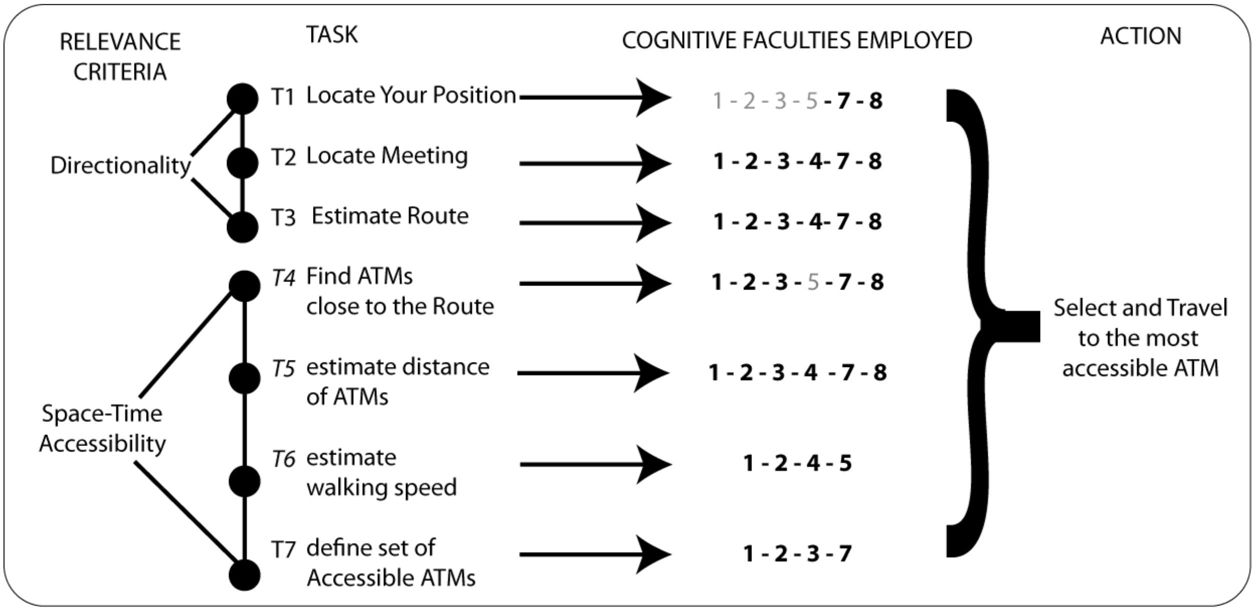

Figure 5 - Tasks related to finding ATMs (Offloaded cognitive faculties are shown in light grey). Numbers for cognitive faculties relate to the list in Figure 1.

5.4. Support by Adapting the Map Representation

Following from this analysis it can be demonstrated that there are many tasks that could possibly be offloaded and possible incorrect inferences are removed. To computationally offload tasks requires a system with basic contextual information about the current location and time in addition to the future location and time of the meeting. Based on this information it is possible to carry out spatial analyses that can be used to inform and adapt the map. A formal method to map adaptation is described by (Raubal and Panov 2008). These spatial analyses effectively replace mental computation that would otherwise have to take place in order to successfully complete the task and are shown below in Figure 5.

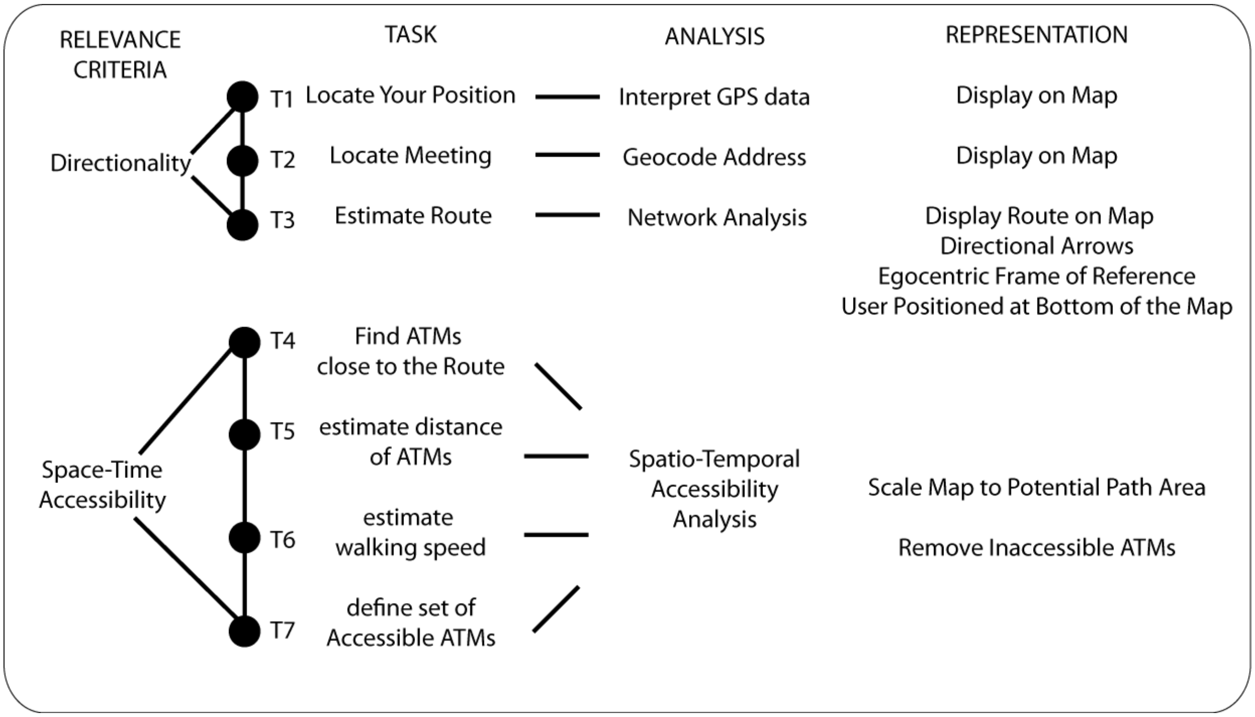

Figure 6 – Relationship between relevance criteria, task, analysis and representation are linked.

This analysis can now be fed into the representational process; the goal of this process is to help the user understand the direction and spatio-temporal accessibility of each ATM. The proposed representation that could possibly increase computational offloading involves mapping the route and destination whilst removing inaccessible ATMs. Additionally adapting the frame of reference to be aligned with the user's given route and putting their location at the bottom of the screen may decrease cognitive load and will additionally help communicate direction (Winter and Tomko 2004). Adapting the map scale to display the extents of the route would also help the user to quickly find a good starting place to begin the information search and find those ATMs relevant to them without the need to pan or zoom. The removal of ATMs that are not accessible within the time budget also contributes to graphical constraining of the representation; the choice set of ATMs within the decision task will always be accessible to the user within the given time limits. Symbolising the destination and user position differently would also constrain against a user believing their current position to actually be the destination. Direction is also something that is familiarly communicated with arrows, as shown by (Tversky and Lee 1999). Therefore adding arrows to convey the route that will be taken will both enhance re-representation and at the same time improve the graphical constraining.

The result of this process is a representation that supports the user's cognition by removing the need to mentally store unnecessary or irrelevant information and carry out mental calculations on it (Figure 6). In general the higher-level cognitive faculties are best supported by this process; the user must still focus his or her visual cognition on the map display for most of these tasks. This is the case for the tasks related to judging directionality. Judging the route no longer requires to perform mental operations relating to positioning one's current location, the destination and the route in between. The need to memorise this information is also eliminated, instead this information is available to be visually analysed at any time. For the second relevance criterion, the spatio-temporal accessibility, some of the tasks (T4 – T6) are completely dispensable. Displaying only accessible ATMs means that no mental calculations as to the distance and how that relates to the travel speed and time constraint will have to be carried out. The decision task following the analysis task would of course still require higher level cognitive processes to be focused on these accessible ATMs but, according to decision theory (Simon et al. 1987), having fewer alternative ATMs to choose from will make this decision less complex. Additionally, explicitly removing inaccessible locations will also help enforce constraints on the decision that may not have been obvious and therefore remove the possibility of a sub-optimal decision being taken.

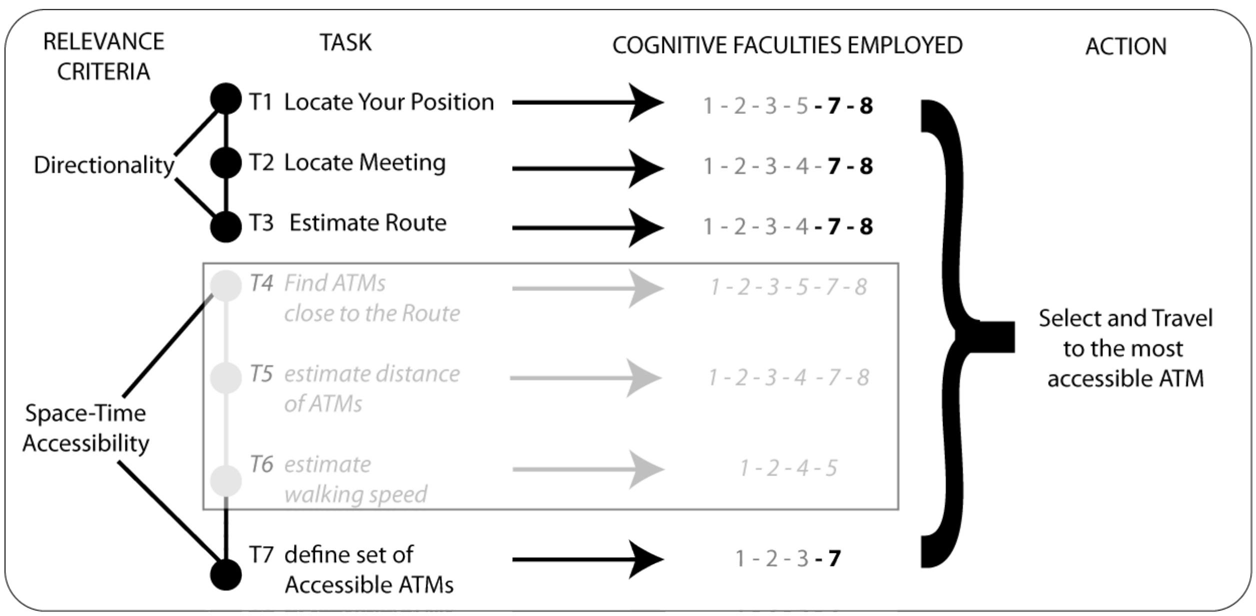

Figure 7 - Tasks related to finding ATMs (Offloaded cognitive faculties are shown in light grey). Numbers for cognitive faculties relate to the list in Figure 1.

After applying this approach and using it to adapt the representation to the tasks the process ends with a map representation that could more efficiently support the tasks required to discover which information is relevant to a user in the above scenario (Figure 7).

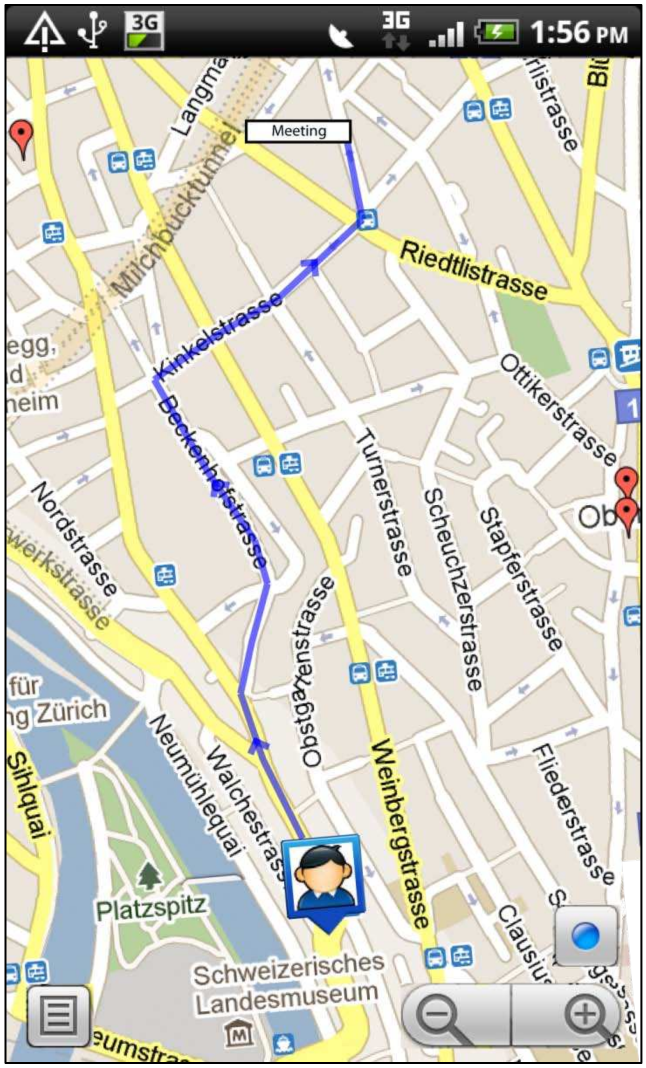

Figure 8 - Adapted Mobile map representation. (Source: http://www.google.co.uk/mobile/maps/#p=default; ©2010 Google)

6. Conclusions and Summary

This study has aimed at illustrating that mobile map displays may be cognitively enhanced through an adaptation to spatial and temporal context. It is argued that to ensure the usability of representations they should be designed to support the cognitive tasks to which they will be applied. This usability results from the transference of mental tasks onto the cartographic representations. This transfer should lower the cognitive load required to interact successfully with the service, something that is important to mobile users whose concentration is frequently focused away from the system itself and towards the surrounding environment (Oulasvirta et al. 2005).

A scenario was used to demonstrate and implement the idea presented; following from this it is evident that further work could be focused in a number of directions. One direction would be to focus on other elements of context other than just space and time, for example the user activity could be investigated and how representations can be adapted to support these activities in a spatio-temporal setting (Miller 2004). Another direction to explore is the range and complexity of spatial concepts that can be communicated. The work of Golledge et al. (2008) is a good indicator of the wealth of geographic concepts, e.g. cluster, co-location, that exist and it is probable that many of them could be valuable to a mobile user seeking relevant locations (De Sabbata 2010). Lastly and most importantly, empirical testing is crucial to validate the ideas presented here and for this reason it will be the first step taken by the authors in the further development of the methodology presented above.

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