A Cognitive Perspective on Spatial Context

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Abstract. This paper develops a representation-theoretic notion of *spatial context* for cognitive agents that interact with spatial environments. We discuss the state of the art in defining context as used in context-aware and / or location-aware systems. In contrast to existing approaches, we define context through cognitive processes. Placing cognitive processes in the focus of our context definition allows for a truly user-centered perspective: conceptualizations imbue spatial structures with meaning. This allows for fixing terminological problems and relating context definitions to work in spatial information theory and cognitive science. Although we focus on spatial context, the approach is generic and can be adapted to other domains in which cognitive aspects concerning users of information systems are central.

1 Introduction

Context has become an omnipresent notion in human-computer interaction (HCI) research. Geographic information systems and services are concerned in particular with *context-aware* or *location-aware* systems. The general idea of context research is to adapt the reasoning of a system / service to current requirements (e.g. location and / or task), and hence, to make the information generated by the system more useful for its user.

It has been considered difficult, however, to define what constitutes context. Popular definitions remain unspecific, and most attempts to fill the concept of context with meaning do it by examples, or – more systematically – by a taxonomy of aspects of context. As a consequence, the list of influencing factors of possible constituents of context get out of hand instead of rendering the concept of context more precise,.

In the present paper we take an orthogonal approach. Rather than decomposing context effects into the different aspects that may play a role we define context in terms of the cognitive architecture that determines the interactions between the components involved. As a starting point, we use cognitive processes that allow for a

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characterization of context, in particular *spatial context*. From such an operational definition of context we expect a better understanding of context effects and on requirements to be taken into account when dealing with context.

The paper is structured as follows: We briefly introduce the notion of context as found in the ubiquitous computing literature and point out weaknesses of current context definitions. On this basis we develop a cognitive architecture for wayfinding problems to exemplify interactions that take place in human spatial problem solving. We discuss the trilateral relationship between an environment, a cognitive agent, and a cartographic map and the interactions that take place between these three entities. On this basis we define *spatial context*. We conclude by discussing possible applications and give an outlook how this approach can be used to overcome deficiencies in more general context definitions.

2 The notion of context in ubiquitous computing

Spatial context came into the focus of research with the concept of ubiquitous computing (Weiser, 1991). Ubiquitous computing aims to provide services everywhere and at any time that take into account features of the actual environment and situation; hence, ubiquitous computing requires information about the environment as well as about the situation and goals of the cognitive agent. For that purpose, ubiquitous computing concepts employ sensors that collect data on the user's location as well as environmental parameters. Interface design research has been aware of the separation of the physical environment and its representation in digital space for a long time (cf. Ishii & Ullmer, 1997). However, this separation usually reflects the provider's perspective and ignores the individual user with her knowledge, abilities, focus of attention, or emotions. For example, a mobile navigation system that only considers the environment and its representation in digital space would neither take into account the cognitive map of the user nor her spatial abilities.

The term 'context' itself has become ubiquitous in the research literature. It is used in combinations such as 'context-aware' systems (Abowd et al., 1997; Dey, 1998; Kjeldskov et al., 2003), or, for specific contexts such as location, in respective combinations such as 'location-aware' systems (e.g., Nicklas et al., 2001; Want & Schilit, 2001; Winter, 2003). The frequently cited survey by Chen and Kotz (2000) clarifies that context-awareness means that applications have to adapt to changing context instead of producing prefabricated content. For example, a (location-aware) mobile navigation system adapts automatically to the changing location of the mobile user and specifies route directions with respect to this location without further user interaction. In contrast, a web service for locating street addresses might come up with a similar map, but will not be considered context-aware since all parameters have to be explicitly specified by the user without taking into account the location at which the query is specified. Other authors distinguish between reactive systems that adapt to the current context, and proactive systems that anticipate future context (Mayrhofer et al., 2003). In any case, time, location, and change play an important role for context.

In this literature, almost all authors agree that it is difficult to define the term ‘context’. A generally accepted definition does not exist and the term is frequently used with unspecific meaning. According to Dey (1998), context is “any information that can be used to characterize the situation of entities that are considered relevant to the interaction between a user and an application, including the user and the application themselves.” To precisiate the concept of ‘context’ the literature has developed taxonomies of aspects that together form context. The influential taxonomy by Schilit et al. (1994) names *spatial context* (where you are), *social context* (who you are with), and *computing context* (what resources are nearby), a taxonomy that is widely considered incomplete (see, e.g., Chen & Kotz, 2000). Alternatively, Dix et al. (2000) distinguish infrastructure context, system context, domain context, and physical context. This illustrates that the categorization of the notion ‘context’ in turn depends on the specific context for which the notion is used; there seems to be no natural categorization of context. Categorizations of context frequently are made ad-hoc without formal methodology, and hence without proof of completeness or relevance.

Some of the aspects of context identified in ubiquitous computing now receive attention in the spatial information theory literature. Among the first is cultural context in cross-language studies (Levinson, 2003; Mark, Skupin, & Smith, 2001; Mark & Turk, 2003). Another one is temporal and spatial context in characterizing the salience of spatial features (Elias, 2003; Winter et al., 2005). This literature typically avoids defining or categorizing specific features of context.

Dix et al. (2000) acknowledge that context-awareness is not a question of a system interface, but of the broader circumstances in which the system is applied, including the physical environment. From that perspective they focus on location. They consider location and environment in terms both of the physical space and its representation in the map system. They implicitly introduce what we will call ‘environment’ by means of nearness and set up an algebraic specification for the type *space*, consisting of location, nearness, and regions, and for the type *world*, consisting of spaces and bodies. With these elements they set up a kind of top-level ontology of spatial context in the environment in the mind of a wayfinder or in the system that computes maps. So far, this is the only formal approach to define spatial context in ubiquitous computing.

Instead of providing a new taxonomy for contexts we will investigate in the following sections how contexts are created and used; this will help us to provide an operational definition of context. When we focus on spatial context, we follow Dix et al. in their argumentation that spatial relations form a fundamental aspect of context for location-aware systems.

3 The relation between spatial environment, cognitive agent, and cartographic map

Let us now render the notion of *spatial context* more precise. In contrast to approaches that are concerned with the potential factors contributing to context, we will detail the cognitive and computational functions of negotiating knowledge in a complex system. This system distinguishes the major components in which these different factors may play a role. We will discuss the roles of spatial contexts in the framework of the trilateral relationship between a spatial environment, a cognitive agent interacting with this environment, and an external representation of that environment (specifically: a map) that the agent may use to support this interaction.

Why are maps useful for our spatial orientation in an environment in which we are immersed and to which we have direct visual access? To answer this question, we will look at the kinds of entities and structures that are involved in solving orientation and wayfinding tasks. We will distinguish between the spatial environment ***E***, in which the orientation or wayfinding task is to be carried out; the cognitive agent ***A*** – a person or a robot – who carries out the task; and the map ***M*** that serves as a tool for performing the task. These three entities are involved in rather sophisticated cognitive interaction processes when we use maps to solve orientation or wayfinding problems.

To reduce the complexity in presenting this trilateral relationship, we will carry out a Gedankenexperiment involving the three entities ***E, A,*** and ***M*** in the paradigm of *synthetic psychology* as introduced by Braitenberg (1984) and discussed for spatial communication with maps, for example by Frank (2000). We will begin with a simple configuration and analyze interaction processes that may take place in this configuration; we then will gradually augment the configuration and we will investigate from a knowledge representation-theoretic perspective in which ways the augmentation influences the interactions. On this basis we develop a representation-theoretic characterization of spatial context applicable to spatial reasoning and spatial interaction.

3.1 An agent without cognition in a spatial environments

The Gedankenexperiment starts by considering a spatial environment ***E*** and primitive agents ***A*** (amoebas or other abulic agents) to whom we would not concede any cognitive capabilities. How do amoebas move in a spatial environment? In a structured environment, their tracks will not be equally distributed random spatial configurations; rather, the tracks will be influenced by the initial position and by the physical structure and the physical forces acting in the environment. For example, if the environment consists of hills and water streams, the movements of the amoebae are guided to follow the spatio-temporal course of the water streams. Those parts of the spatial environment that influence the motion of the amoeba belong to the spatial situation context of the amoeba. The abulic agent completely depends on the *affordances* of the environment that will determine where they move (cf., Gibson, 1979). This can be regarded as a weak version of "knowledge in the world" (e.g., Norman, 1980; Raubal & Worboys, 1999); it also can detail the very origin of this knowledge.

Although we discuss movements in our Gedankenexperiment, we will not emphasize the issue of temporal context and of changing knowledge about the environment, here,

3.2 A cognitive agent without mental representation of its spatial environment

How does the situation change when we replace the primitive agent by a cognitive agent – specifically by a human being or a cognitive robot? The physical affordances of the environment will still determine to a large extent where the agent will move (see Fig. 1): one of the fundamental aspects of affordance, of course, is gravity; it will keep the agent on the ground, for the most part. Other aspects are passages that are easy to traverse and obstacles that will prevent the agent from moving to certain places. Besides the affordances imposed by the environment certain affordances are imposed by size, shape, and abilities of the agent: the agent can perform certain movements on the basis of its anatomy and physiology; certain other movements are not possible. In general, affordances are determined by the *interaction* between agents and their environments: for instance, the size of an agent interacts with the size of a passage: the relationship between these sizes will determine the affordance of certain movements between the agent and the environment.

Fig 1. Affordances emerge in the interaction between environment (E) and agent (A).

Let us now consider the cognitive side of the agent: the agent wants to move to some specific location in the environment, say to the exit of the building he is in. Agents with low-level cognition (e.g., insects or reactive robots) may employ rather primitive reactive mechanisms to move to their destination that do not require an internal representation of their environment in their minds (e.g., Brooks, 1991); thus, simple cognitive affordances relating to the agent's perception and action capabilities can be engaged in addition to the purely physical affordances discussed in the previous section.

3.3 A cognitive agent with mental representation of its spatial environment

Higher cognitive animals like rats, humans, or cognitive robots build up internal representations of their environment (frequently referred to as *cognitive maps*) that help them to plan and control their movements in space (see Fig. 2). If a wayfinder's destination is not directly accessible to perception, a mental representation that functions as a memory for the structure of the environment is necessary to plan and carry out actions that will get the agent to its destination. Certain aspects of the spatial structure of the environment are represented in the memory of the cognitive agent to allow him, her, or it to reflect about the world and to plan actions to be carried out in the spatial environment.

Why is it economical to represent aspects of the world in which we are immersed? The answer is simple: if we can use a mental representation as a model of an environment we can carry out certain operations *mentally* that would otherwise require physical actions in the spatial environment itself. Besides the savings of *physical energy* and *time* through mental operations, there may be advantages due to suitable representation structures (Sloman, 1985), as these mental structures are not replicas of the environment. In addition, mental operations may be much less dangerous and harmful than the corresponding physical actions.

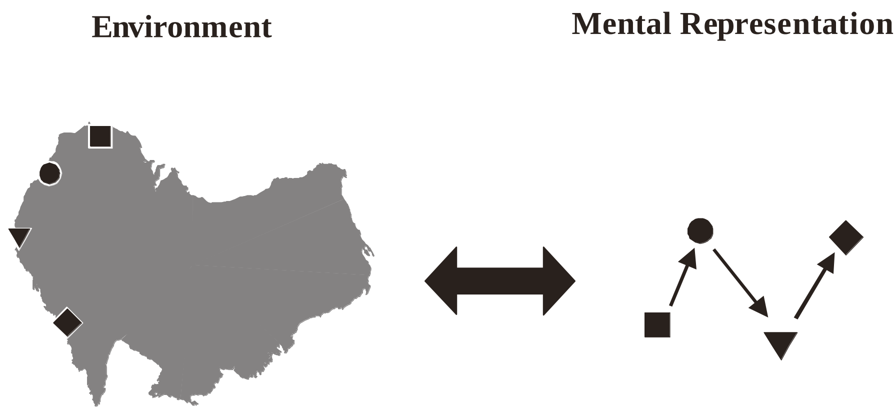

Fig. 2. Two worlds and a representation (correspondence) relation (cf. Palmer, 1978). In this example the arrows indicate the relation 'further north than'.

In short: we have information about the spatial environment twice: in the world and in the mind. The two information sources are connected through a *representational correspondence* (Palmer, 1978). Certain tasks are achieved more economically by taking a 'shortcut' through the mental representation than by taking action in the environment.

3.4 A cognitive agent with mental representation of its spatial environment and a map

From the perspective of *cognitive architecture* the situation becomes much more complex when a map as a third element is integrated. If information about the environment is available in two incarnations – in the environment and in its mental representation – why do we need maps to find our way? A map is a third source of information about the spatial environment besides the two we dealt with in the previous section. The answer is simple again: a map enables a cognitive agent to solve spatial problems that he can solve neither by inspecting the environment nor by inspecting its mental representation.

A map can replace neither the environment nor its mental representation; however, a map can extend our cognitive capabilities in certain settings (e.g., Scaife & Rogers, 1996): (1) a map can provide information about environments which we are not immersed in and / or which we have never seen before; (2) a map can provide information about environments we have seen before but whose details have escaped our mind; and (3) a map can provide information about environments we are immersed in for which it may be difficult or impossible to get an overview; it enables us to get a global view of the environment that allows us to apply certain spatial reasoning mechanisms. Thus, a map can extend our mental representation of an environment and our mental representation can interact with this external representation to extend the range of problems we can solve.

We now have three sources of information about the spatial environment: the environment ***E*** itself, the mental representation of the agent ***A***, and the external representation in form of a map ***M***. The three information sources each are in a correspondence relation to the other two; these relations are depicted in Fig. 3:

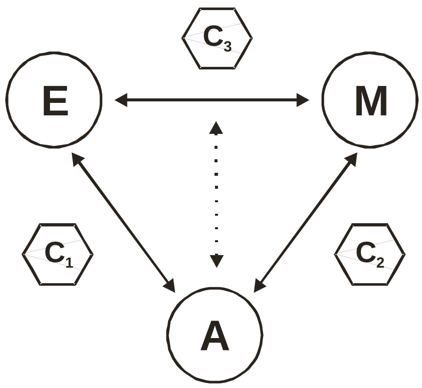

Fig. 3. The relation C1 establishes a correspondence between the environment ***E*** and the mental representation of agent ***A***; C2 establishes a correspondence between this mental representation and the map ***M***; and through composition of C1 and C2, C3 sets some aspects of the environment ***E*** in relation to the map ***M***.

The correspondences between the three sources of spatial information are established in different ways: C1 is more or less hardwired by means of the agent's sensory organs and / or established in early phases of getting acquainted with spatial environments (e.g., Clark, 1973; Wilson, 2002); in humans, the correspondence established by our perceptual / cognitive machinery becomes so strong that we sometimes are unable to distinguish between 'what is out there' in the real environment and what we know about it; a single correspondence relation is established.

The relation C2 is different in that it is not specified by the development of the perceptual apparatus: making and interpreting external representations of mental images is an art cognitive agents develop much later and there is not one ‘natural’ way of externalizing mental images or of interpreting external spatial representations. A variety of correspondence relations can be established here. A map can be conceived of as an abstract picture that can be interpreted in different ways and independently of the represented environment. A cognitive agent can use a map to reason about spatial relations even if no corresponding spatial environment exists; the relation C2 can be substituted for the relation C1 in such a way that the map becomes the target spatial environment or the representation of a fantasy world.

The correspondence relation C3 between the environment and the map representation is different again: it is established by the agent on a high cognitive level by composing the relations C1 and C2. An external depiction of something is never a representation by virtue of the intrinsic properties of the ‘something’ and the depiction; it becomes a representation by explicitly establishing correspondence relations (Furbach et al., 1985; Palmer, 1978).

As we pursue a cognitive perspective, we will only consider cognitively relevant aspects of these three entities with respect to the spatial tasks to be solved. In the environment ***E***, these are the locations of physical objects present, their spatial relations with respect to each other, their shape and other properties of appearance, their visibility, their uniqueness and / or their distinctiveness in the environment, and possibly further aspects. Regarding agent ***A***, we are concerned about (1) perceptual spatial abilities (specifically vision and audition, and possibly the sense of smell); (2) spatial memory abilities (specifically the ability to remember previously perceived environments and / or representations of environments); (3) abstraction abilities (in particular: abilities to develop a mental image of a real environment, to generate and interpret maps, and to relate the different representations); (4) imagery abilities (mental ‘visualization’ of those memories); (5) mental reasoning abilities (transformation of perception and memories into other forms); (6) spatial action abilities (the transformation of new insights about the spatial environment into physical actions in the environment; (7) spatial interaction abilities (abilities to communicate with other cognitive agents about spatial situations); these abilities involve (8) abilities to relate and integrate spaces of different scale and type: table top space, vista space, environmental space, ... (Montello, 1993) and (9) abilities to employ different spatial reference systems (Levinson, 1996) and to transform from one reference system to another. In the map ***M,*** we are concerned about adequate symbols and relations for depicting and interpreting spatial relations in a consistent and unambiguous way.

3.5 Cognitive processes related to the three spatial information sources

So far, we discussed representational correspondences as if they were static relationships. However, in as far as they are established by cognitive *processes*, we should point out the importance of dynamic aspects in establishing representational correspondences in spatial domains. The affordances of the spatial environment determine to a large extent how people perceive an environment, as we interpret the world largely in terms of its functions and its presumed 'purposes'. They are important to generate expectations about what will or what might happen next. For humans, a small pathway in a meadow may be more salient and memorable than large branches of a tree while for birds and monkeys it may be the other way around; thus actual or potential actions and events structure the environment into relevant and irrelevant aspects (e.g., Richardson & Spivey, 2000).

The actions and events that may take place in the environment are reflected in mental capabilities in human mental representations: we can *imagine* the same type of actions and events mentally; in fact, it is much easier for us to imagine realistic events like a person walking down a pathway by mental simulation than fictional events like the disintegration or reconfiguration of the environment. Similarly, we use external maps to *physically* simulate actions like journeys by moving our finger across the line symbols that correspond to the pathways of the journey in the real environment or we *mentally* simulate such actions by traversing these line symbols with our visual perception and attention apparatus.

These examples and other evidence suggest that the spatial correspondence between different information sources is particularly useful for establishing a direct process correspondence between processes in the spatial environment, perceptual attention processes in vista space and table-top space, mental imagery processes, and manipulation processes in table-top space (Freksa, 2004).

4 Spatial context

In the foregoing sections we established a general representation-theoretic framework involving a spatial environment, one or more cognitive agents, and external representations of the spatial environment; we will now use this framework to characterize various types of *spatial context* without differentiating between different aspects that may be involved in these contexts; instead, we will distinguish types of contexts on the basis of their role in the framework.

It is evident that in different cognitive domains different aspects are relevant and therefore different contexts apply; in our case we are interested in contexts in the environment, in the mental representation of the agent, in the external map representation, and in their mutual interactions. In the following, we will briefly sketch examples of such contexts. Again, we will stress the interaction between different entities in the architecture of a complex cognitive system involving the spatial environment, the cognitive agent, and an external representation structure. In this way, the agent will be the focus of attention as he contributes the cognitively active parts of the overall system. Contexts are then determined through cognitive functions that are involved in the interactions of the architectural components. To this end it becomes possible to relate the definition of (spatial) context to work in cognitive science and approaches of research on ontologies. A process-oriented characterization of context is a necessary requirement for the integration of context concepts in modern information systems. We will provide a short classification of spatial contexts and exemplify their role for the domain of wayfinding.

4.1 Situation context

The spatial situation context of an object or of an agent is the spatial structure in the physical environment that this object or agent is embedded in. The available physical, perceptual, or cognitive processes will determine which structures influence a given situation and thus must be considered as part of the respective spatial context. For example, the relevant situation context for the movements of an amoeba consists of those spatial structures in the spatial vicinity of the amoeba that affect its motion pattern. For cognitive agents, the relevant spatial situation context varies depending on the focus if interest: are we interested in visual influences, auditory influences, or in the agent's disposition with respect to air flow and its temperature, or in a combination of various relevant factors. From a cognitive perspective we would argue that the relevancy of factors is determined by their role for the conceptualization process of the cognitive agent, i.e. the instantiation of a representation that takes into account several sources. This form of representation has been discussed under various names, for example, *current conceptual representation* (Habel, 2003), *conceptual structure* (Jackendoff, 1997), *current spatial representation* (Klippel et al., 2003). We will briefly describe the approaches from the domain of wayfinding and route directions that exemplify a formalization of simple conceptualization processes.

Duckham and Kulik (Duckham & Kulik, 2003) expand an approach by (Mark, 1985) on calculating a simplest paths. The general idea is to find a path in a network of paths that matches the criterion of being easy to describe. This approach is in contrast to other approaches that calculate, for example, the shortest connection between two locations. Conceptualization processes are a precondition for (verbal) descriptions of routes and verbalizations can be used as a window to these conceptualizations. The formalization of the "ease of description" by Mark (1985) can therefore be seen as a formalization of a conceptualization process, hence providing a formal description of a spatial context in the sense used in this article. The frame with slots that Mark uses for the characterization of actions at intersections and corresponding descriptions is the specification of a spatial context.

A similar yet antipodal approach is taken by Richter and Klippel (2005). Instead of providing a single description for finding the best matching paths in a network, a variety of descriptions is given to find the best conceptualizations for a given route. Each conceptualization is suited to identify and characterize a spatial context.

4.2 Mental context

Processes in the mental representation of spatial environments are affected not only by perceptions of the environment but also by activated memory contents (e.g., Baddeley, 1986). For example, if a human cognitive agent has been mentally engaged in the dangers of wildlife, she or he will be more likely to suspect and associate dangerous creatures with natural spatial environments than otherwise. This mental spatial context may be activated by certain features in the environmental context, but it is independent of the fact whether or not wild animals actually exist in the perceived environment.

4.3 Map context

Accordingly, map context relates to spatial entities in the map that may affect the map generation and interpretation processes. For map generation, these may be entities that influence the map generalization process; for map interpretation, these may be entities that capture the map reader's attention.

4.4 Other contexts relevant in spatial reasoning, action, interaction

Our representation-theoretic characterization was restricted to the three sources of spatial information ***E, A,*** and ***M***. However, if we augment the model, for example to include natural language as a source of information about space, a *language context* will get involved.

Not only the system components themselves but also their interactions can be used to define contexts. For example, an experienced map reader will apply different map interpretation processes than a novice; thus, the substructure (Frank, 2000) defines a context in which certain interpretations are generated while others are not. Or in the communication between two agents that each engage their own language with personal vocabulary and personal background knowledge, a specific communication context is created in which certain types of exchanges that are suited to this context are generated while others are not.

5 Application

In a more or less static environment the location of the wayfinder will change during a physical wayfinding process; thus, at least the location is of spatio-temporal nature. A *location-aware*, *location-adaptive*, or *location-based* system interacts with the wayfinder *and* reacts to a change of her location at the same time. This means that location is used with the characteristics of a context as defined in the ubiquitous computing literature.

Location *per se* is not a context. We can assume location to exist independently of a perceiving mind. But it is the perceiving mind that identifies gestalt and affordance in the signals of perceptions of the environment and applies cognitive processes to focalize (Bal, 1997) experience of space either in internal cognitive representations or in external representations. In other words, the focalizer uses location to create a spatial context. Thereby the same location can be used to create different spatial contexts.

We will now discuss the creation of spatial context from location by our process-oriented perspective, applying the principles introduced above.

5.1 Location and environment

Each subject (wayfinder) and object (e.g., her mobile device) has a unique location in the physical world at each point in time. This location can be specified in terms of a three-dimensional body in relation to the rest of the spatial environment. Each body can be imposed with axes, giving it an orientation, and a center (frequently abstracted as position of the entire object). We consider location to specify a relation to other objects, while position specifies a relation in an (otherwise empty) reference frame. Location and position can be determined by perception and / or computation. Bodies can move, and thus, location can change. Individual body movements can be quite complex, and hence, are typically generalized and abstracted in mental representations (e.g., {activity, start, end} or {activity, start, direction}) and external representations (e.g., trajectories).

5.2 Location and wayfinder's mind

The perceiving mind of a wayfinder focalizes location into a spatial context of *I-am-here*. The internal spatio-temporal concept of *I-am-here-now* extremely depends on other contexts. A child playing hide-and-seek will have a relatively detailed idea of I-am-here, and a person experiencing 'Europe-in-ten-days' will have a relative coarse idea, maybe two-dimensional if not one-dimensional (see also Read & Budiarto, 2003), even if both share the same location. They have a different perspective on their immediate environment, and they perceive different entities in their environment, in terms of potential activities. The same is true, for example, for a pedestrian and a bicyclist, who are at the same location.

A primitive agent without cognitive capabilities (see Section 3.1) is a purely reactive agent. Sensed physical affordances lead to hard-wired motor actions. With no cognitive processes involved, the agent is located, but establishes no spatial context.

A cognitive agent without a mental representation of its environment can perceive gestalt and affordances (see Section 3.2), and will focalize perceptions at least to a level of planning and controlling future actions. Spatial context is minimal, but depends fully on these cognitive processes; these processes, in turn, depend on the embodiment of the cognizer: a wheeled robot plans and controls actions differently then a legged robot, for example.

A cognitive agent with mental representation of her environment (see Section 3.3) focalizes perceptions to an internal representation; the agent establishes representations of the relationships of her body to other bodies in the environment depending on current cognitive processes. Hence, location is transformed in (complex) spatial context.

5.3 Location and external map

An external map represents location of a moving agent typically by reducing the notion to position. A familiar representation of position on a map is a point in a two-dimensional space, a projection of the earth's surface to a plane surface. The point is characterized by coordinates in a specific spatial reference system (the mapping system), and possibly by a covariance matrix describing positional accuracy. In an alternative form of representation, position can be characterized qualitatively (e.g., in sketch maps).

In these cases, location is constructed by means of positioning techniques. The location of the mobile positioning device is only an approximation of the location of the wayfinder, since they are two different bodies and use two different sensing techniques to derive their position. Depending on the respective positioning technology of a device, its position can be represented by GPS coordinates, cell IDs of a wireless communication network, or coordinates matched to a particular travel network (Schiller & Voisard, 2004; Scott-Young & Kealy, 2002). Furthermore, the current location of the positioning device – which becomes the location on the map – can differ from the location represented on the map, due to inaccurate or outdated positioning.

So far, we have considered position as a representative of location. Nevertheless, by putting the position on a map the map making agent establishes relations between represented objects and the current position of the agent. The agent does this by applying cartographic variables like selection, accentuation, generalization, or displacement. The controlled application of these variables is, again, focalization, based on cognitive processes.

6 Conclusions

Nevertheless, the definitions of context hedge to render the term more precise and rather add aspects to it. The current paper tried a different approach by focusing on spatial context and relying on cognitive processes as a means for defining context. The general approach taken is a representation-theoretic characterization of the trilateral interactions that take place when a cognitive agent is active in an environment aided by a map-like representation.

In this article we considered the notion of spatial context in terms of cognitive processes involved in the interaction between cognitive agents, spatial environments, and cartographic maps. Defining spatial context through cognitive processes (especially spatial cognitive processes) allows for the integration of several currently discussed topics, for example, principles of embodied cognition, such as cognitive off-loading (Wilson, 2002), that are regarded as most useful in spatial tasks. Our approach develops a framework for context to demonstrate the relationships between environmental spatial context, mental spatial context, and map spatial context for a wayfinder.

The presented formal method constitutes an operational approach to characterize specific spatial contexts involved in cognitive interactions. Our method does not incorporate user studies regarding specific features or aspects that may have to be taken into account in cognitive modeling; rather, it presents the architecture of a model for cognitive processing into which the results of such studies easily can be incorporated. Categories of context are formed through the type of knowledge engaged in the cognitive processes, not by ad-hoc decisions. This representation-theoretic approach makes the representation relations between different cognitively relevant domains explicit and can be applied to other aspects of context equally well and will clarify the notions of context in the corresponding approaches.

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References

Abowd, G. D., Atkeson, C. G., Hong, J., Long, S., Kooper, R., & Pinkerton, M. (1997). Cyberguide: A Mobile Context-Aware Tour Guide. *ACM Wireless Networks, 3*(5), 421-433.

Baddeley, A. D. (1986). *Working memory*. New York: Oxford University Press.

Bal, M. (1997). *Narratology: Introduction to the Theory of Narrative* (Second Edition ed.). Toronto: University of Toronto Press.

Braitenberg, V. (1984). *Vehicles. Experiments in synthetic psychology*. Cambridge, MA: MIT Press.

Brooks, R. (1991). Intelligence without representation. *Artificial Intelligence, 47*, 139-160.

Chen, G., & Kotz, D. (2000). *A Survey of Context-Aware Mobile Computing Research* (Dartmouth Computer Science Technical Report TR2000-381). Hanover, NH: Department of Computer Science, Dartmouth College.

Clark, H. H. (1973). Space, time, semantics, and the child. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 28-63). New York: Academic Press.

Dey, A. K. (1998). *Context-Aware Computing: The CyberDesk Project*. Paper presented at the AAAI '98 Spring Symposium, Stanford, CA.

Dix, A., Rodden, T., Davies, N., Trevor, J., Friday, A., & Palfreyman, K. (2000). Exploiting space and location as a design framework for interactive mobile systems. *ACM Transactions on Computer-Human Interaction, 7*(3), 285-321.

Duckham, M., & Kulik, L. (2003). "Simples" paths: Automated route selection for navigation. In W. Kuhn, M. Worboys & S. Timpf (Eds.), *Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT) 2003.* (pp. 182-199). Berlin: Springer.

Elias, B. (2003). Extracting Landmarks with Data Mining Methods. In W. Kuhn, M. F. Worboys & S. Timpf (Eds.), *Spatial Information Theory* (Vol. 2825, pp. 398-412). Berlin: Springer.

Frank, A. U. (2000). Spatial communication with maps: Defining the correctness of maps using a multi-agent simulation. In C. Freksa, W. Brauer, C. Habel & K. F. Wender (Eds.), *Spatial cognition II: Integrating abstract theories, empirical studies, formal methods, and practical applications*. Berlin: Springer.

Freksa, C. (2004). Spatial Cognition - an AI perspective. In R. López de Mantaras & L. Saitta (Eds.), *ECAI 2004*. Amsterdam: IOS Press.

Furbach, U., Dirlich, G., & Freksa, C. (1985). Towards a theory of knowledge representation systems. In W. Bibel & B. Petkoff (Eds.), *Artificial intelligence methodology, systems, applications* (pp. 77-84). Amsterdam: North-Holland.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Habel, C. (2003). *Incremental generation of multimodal route instructions*. Paper presented at the Natural Language Generation in Spoken and Written Dialogue, AAAI Spring Symposium 2003, Palo Alto, CA.

Ishii, H., & Ullmer, B. (1997). *Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms*. Paper presented at the Conference on Human Factors in Computing Systems (CHI '97), Atlanta.

Jackendoff, R. (1997). *The architecture of the language faculty*. Cambridge, MA: MIT Press.

Kjeldskov, J., Howard, S., Murphy, J., Carroll, J., Vetere, F., & Graham, C. (2003). *Designing TramMate – a context aware mobile system supporting use of public transportation*. Paper presented at the Designing User Interface 2003 Conference, San Francisco, CA.

Klippel, A., Tappe, T., & Habel, C. (2003). Pictorial Representations of Routes: Chunking Route Segments during Comprehension. In C. Freksa, W. Brauer, C. Habel & K. F. Wender (Eds.), *Spatial Cognition III. Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Learning*. (pp. 11-33). Berlin: Springer.

Levinson, S. C. (1996). Frames of reference and Molyneux's question: Cross-linguistic evidence. In P. Bloom, M. Peterson, L. Nadel & M. Garrett (Eds.), *Language and Space* (pp. 109-169). Cambridge, MA: MIT Press.

Levinson, S. C. (2003). *Space in Language and Cognition*. Cambridge: Cambridge University Press.

Mark, D. M. (1985). Automated route selection for navigation. *IEEE Aerospace and Electronic Systems Magazine, 1*, 2-5.

Mark, D. M., Skupin, A., & Smith, B. (2001). Features, Objects, and Other Things: Ontological Distinctions in the Geographic Domain. In D. R. Montello (Ed.), *Spatial Information Theory* (Vol. 2205, pp. 489-502). Berlin: Springer.

Mark, D. M., & Turk, A. G. (2003). Landscape Categories in Yindjibarndi. In W. Kuhn, M. F. Worboys & S. Timpf (Eds.), *Spatial Information Theory* (Vol. 2825, pp. 28-45). Berlin: Springer.

Mayrhofer, R., Radi, H., & Ferscha, A. (2003). *Recognizing and Predicting Context by Learning from User Behavior*. Paper presented at the International Conference On Advances in Mobile Multimedia (MoMM2003), Linz, Austria.

Montello, D. R. (1993). Scale and multiple psychologies of space. In A. U. Frank & I. Campari (Eds.), *Spatial information theory: A theoretical basis for GIS*. (pp. 312-321). Berlin: Springer.

Nicklas, D., Großmann, M., Schwarz, T., Volz, S., & Mitschang, B. (2001). A Model-Based Open Architecture for Mobile, Spatially-Aware Applications. In C. S. Jensen, M. Schneider, B. Seeger & V. J. Tsotras (Eds.), *Advances in Spatial and Temporal Databases* (Vol. 2121, pp. 117-135). Berlin: Springer.

Norman, D. A. (1980). *The Psychology of Everyday Things*. New York: Basic Books.
Palmer, S. E. (1978). Fundamental aspects of cognitive representation. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization* (pp. 259-303). Hillsdale, NJ: Lawrence Erlbaum.
Raubal, M., & Worboys, M. (1999). A formal model of the process of wayfinding in built environments. In C. Freksa & D. M. Mark (Eds.), *Spatial information theory. Cognitive and computational foundations of geographic information science*. (pp. 381-399). Berlin: Springer.
Read, S., & Budiarto, L. (2003). *Human scales: Understanding places of centering and de-centering*. Paper presented at the Fourth International Symposium on Space Syntax, London, UK.
Richardson, D. C., & Spivey, M. J. (2000). Representation, space and Hollywood Squares: Looking at things that aren't there anymore. *Cognition, 76*, 269-295.
Richter, K.-F., & Klippel, A. (2005). A model for context-specific route directions. In C. Freksa, M. Knauff & B. Krieg-Brueckner (Eds.), *Spatial Cognition IV. Reasoning, Action, and Interaction: International Conference Spatial Cognition 2004* (pp. 58-78). Berlin: Springer.
Scaife, M., & Rogers, Y. (1996). External cognition: how do graphical representations work? *International Journal of Human-Computer Studies, 45*, 185-213.
Schilit, B., Adams, N., & Want, R. (1994). *Context-Aware Computing Applications*. Paper presented at the IEEE Workshop on Mobile Computing Systems and Applications, Santa Cruz, CA.
Schiller, J., & Voisard, A. (2004). *Location-Based Services*. San Francisco: Elsevier.
Scott-Young, S., & Kealy, A. (2002). An Intelligent Navigation Solution for Land Mobile Location Based Services. *Journal of Navigation, 55*, 225-240.
Sloman, A. (1985). Why we need many knowledge representation formalisms. In M. Bramer (Ed.), *Research and development in expert systems, Proceedings BCS Expert Systems Conf. 1984*. Cambridge, MA: Cambridge University Press.
Want, R., & Schilit, B. (2001). Expanding the Horizons of Location-Aware Computing. *IEEE Computer Journal, 34*(8), 31-34.
Weiser, M. (1991). The Computer for the Twenty-First Century. *Scientific American*(9), 94-104.
Wilson, M. (2002). Six view on embodied cognition. *Psychonomic Bulletin and Review, 9*, 625-636.
Winter, S. (2003). Route Adaptive Selection of Salient Features. In W. Kuhn, M. F. Worboys & S. Timpf (Eds.), *Spatial Information Theory* (Vol. 2825, pp. 320-334). Berlin: Springer.
Winter, S., Raubal, M., & Nothegger, C. (2005). Focalizing Measures of Salience for Wayfinding. In L. Meng, A. Zipf & T. Reichenbacher (Eds.), *Map-based Mobile Services - Theories, Methods and Implementations* (pp. 127-142). Berlin: Springer Geosciences.