Intelligent Spatial Communication

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Abstract

People can give better route advice to a wayfinder than current navigation services due to many reasons, among them their more compatible spatial conceptualizations based on a common embodied experience of space, and their situatedness during communication, enabling them to make inferences to capture and adapt to context. So, how far are current navigation services from imitating humans in giving route directions? And what can we learn from this question, in terms of need for further research to build more intelligent services? This paper aims for a systematic framework to develop a research agenda for services to give better route directions. The framework is developed from various perspectives on human wayfinding communication.

1 Introduction

Consider the simple question of a person: “Can you tell me the way to ...”, which leads to typical everyday communication either with other persons or with a computing machine in form of a dedicated navigation service. However, current navigation services are frequently criticized for not adapting to the user’s needs and language (e.g., Timpf 2002; Pontikakis 2006).

Recent progress in technology has evolved along two directions. One is towards dynamic proliferation of more content, such as real-time traffic

G. Navratil (eds.), *Research Trends in Geographic Information Science*,
Lecture Notes in Geoinformation and Cartography, DOI 10.1007/978-3-540-88244-2_16,

data, points of interest, or find-and-recommend services. The other is towards more complex interfaces, such as perspective views, 3D, textures, or multi-modal information. These developments seem to counteract easing the cognitive workload of the user, and hence, the question arises whether more intelligent services can evolve at all from these directions of current development. With other words, does research and development need a correction of perspective? This chapter sets out to study what makes a truly intelligent navigation service.

Turing, laying the ground for what later became known as artificial intelligence, starts his landmark paper *Computing Machinery and Intelligence* with the words: "I propose to consider the question, 'Can machines think?'" (Turing 1950, p 1). This question seems appropriate in the current context, where we are seeking what can make navigation services intelligent. In this sense we take the liberty to restrict Turing's question by asking "Can machines think spatially?".

Already Turing himself was aware of the problem of defining thinking or intelligence. He came up with an elegant suggestion: an anthropomorphic imitation game, which was later called the *Turing test*. In this game persons at a teletype interface are supposed to find out whether they are communicating with a machine or another person. Turing equaled anthropomorphic communication behavior with being intelligent. If the player cannot distinguish between machine and person the machine passes the Turing test.

We may borrow from this idea. Translated into our context, a machine can show intelligent spatial communication behavior if persons, requesting some route information from the machine, cannot find out whether they are communicating with a navigation service or with another person. Accepting modern forms of human computer interaction, and extending Turing's rules of communication, we allow for graphical (Egenhofer 1997; Agrawala and Stolte 2001) and gestural (Kopp and Wachsmuth 2004; Cassell et al. 2007; Roth 2007) communication interfaces, since people may describe routes graphically and by gestures as well. We also allow for mobile devices that can be taken into the wayfinder's decision situation, which enables, in principle, to catch the communication context.

Contrary to Turing's own expectations the machine has not yet passed the Turing test. Even restricted versions are still a challenge. Others have limited the scope of the Turing test before. For instance, the Loebner Prize[1] is awarded annually to a program that passes a Turing test *of limited scope and tenor*. In our context, the *scope* would be restricted to the domain of orientation and wayfinding. We do not require a navigation service to be intelligent about other domains, let us say, football or food. Also, the *tenor*

[1] http://www.loebner.net/Prizef/loebner-prize.html

would be restricted to a natural discourse in this domain. We do not expect navigation services to cope with attempts to be outwitted or with comments out of context.

The communication behavior of a navigation service can be tested for the *information content*, either requested or conveyed, i.e., whether it is talking about appropriate routes, and for the *form of communication*, i.e., whether it is understanding the user's spatial descriptions and is responding in terms and references a person would choose (Allen 1997). But even a service that behaves reasonably well content-wise and language-wise on standard requests requires flexibility to be able to follow the course of a natural conversation on orientation and wayfinding. Persons may come with a variety of requests such as for more detail on a route, for alternative routes, for confirmation of their understanding of a route description, for comparisons or assessments, for clarifications of perceived inconsistencies, or for context-dependent additional information such as fares or kinds of tickets.

Spatial communication fails to be intelligent every time when an anthropomorphic quality in a service's communication behavior is detected missing. Since the total number of missing qualities cannot be determined in advance, it is impossible to prove that a machine can behave in their spatial communication like a person. But each closure of an identified gap forms a refutation of the hypothesis that machines cannot behave like a person – until the next gap is detected.

Looking at intelligent spatial communication this way, it provides a vision of an intelligent navigation service, something that current progress of technology is lacking. The aim of this paper is to establish a formal framework that will enable us to study the state of the art, and especially the gaps towards intelligent navigation services.

This paper starts with a review of the Turing test. It then lays out a framework to analyze intelligent spatial communication by studying the human wayfinding communication process from different perspectives. The first perspective looks at the phases of the communication. The second categorizes the elements of the spatiotemporal context of a wayfinding communication. The third perspective is taken by identifying characteristics of an intelligent agent for the communication partner of the wayfinder. The paper will conclude with a summary and outlook.

2 A Criterion for Intelligent Spatial Communication

When Turing (1950) suggested the anthropomorphic imitation game he was interested in finding a simple operational definition of intelligence. Nevertheless, his suggestion of the game (now called *Turing test*) sparked an ongoing controversy in artificial intelligence and beyond[2]. This controversy entwines around the notion of *thinking* or *intelligence*.

So, is it *intelligent* if the computer imitates a person successfully? Philosophers, for example Searle, insist that thinking requires a mind and consciousness. Searle's Chinese Room experiment (1980) basically says that a computer programmed to do a task (here: understanding Chinese) could also be replaced by a person running this computer program by hand. In his example the task is translating a Chinese text into English. As this person does not understand Chinese, nor does the computer. With other words, computers are mindless; they manipulate symbols in an order they were programmed. Already Lady Lovelace (1815–1852) realized that machines can only do what we have the skill to tell them to do (after Turing 1950). Even though a program adds abilities and programmers' knowledge to a computer, potentially including an ability to learn and hence to act in ways not predictable by their programmers, this teaching of abilities and knowledge only means a computer can be appropriately programmed to pass the Turing test, without a chance to claim having consciousness or a mind. Searle calls the former *weak* AI, and the latter *strong* AI, linking only strong AI to thinking and intelligence. Obviously the Turing test relies only on the communication behavior, i.e., the cognitive and linguistic performance capacities of a computer. It does not require to look like or to internally function as a human. Accordingly, we will abstain in the following from using the word thinking, and render our expectations more precisely as an imitation of a person's spatial communication behavior. This means we call a service intelligent if it appears to behave in its spatial communication like an intelligent agent: a person.

But the initial question can also be phrased slightly different. People may ask whether the computer is not more intelligent than a person anyway, so why bother with imitating? Where this question comes up, the objectivity of a computer and its large and accurate data sets seems to be able to generate more trust in spatial advice than a fellow citizen. However, this question shifts the focus from intelligent behavior to behavior superior to the human mind. The computer is superior to the human mind in at least two ways:

- A persistent and large memory enables a computer theoretically to access a complete and accurate travel network data set for route computation. This data set can be even kept up-to-date in real time by distri-

[2] French (2000) observed that Turing's paper became the most discussed paper in artificial intelligence, and Crockett (1994, p 1) notices: "Andersons's 1964 anthology, Minds and Machines, places Turing's paper first, perhaps following the ancient Semitic practice of placing the most important literature in a collection first".

buted sensors. A person is always bound to knowledge acquired by experience over time. This knowledge is subjective, selective, and historic.
- Algorithms to compute optimal routes can be shown to be theoretically correct, i.e., if an optimal solution exists at a particular time such an algorithm will find it, although it may take a long time. A person is bound to distorted cognitive spatial representations (Stevens and Coupe 1978), and human route selection is habitual and applies heuristics that potentially lead to suboptimal routes (Golledge 1999).

Now, superiority, once detected by a human communication partner, leads to failure in the Turing test. With other words, in Turing's sense it is not considered to be intelligent. Although this conclusion may surprise, there are arguments why an intelligent navigation service should not demonstrate its superiority. These arguments are based on cognitive costs, as will be discussed in the following.

First, in an inherently uncertain world it has an advantage why people do not (always) select the route optimal according to a cost function. Their selection is based on heuristics. Gigerenzer (2007) calls such heuristics convincingly the intelligence of the unconscious, referring to the delusion of finding an optimum in an uncertain world. Even a computer is limited in finding an optimum route facing the unpredictability of travel times in the future. People may favor simple paths or familiar ones and by this way ease their wayfinding process, including the communication of the route.

Secondly, in an inherently complex world it has another advantage to apply heuristics. A computer may take longer to solve some routing tasks exactly than it takes a person to find an acceptable suboptimal solution (Dry et al. 2006; Applegate et al. 2007).

Thirdly, short term memory is limited. Communicating by maps, metric information, perspective views or virtual reality animations – showing as much detail as possible, as many navigation services do – comes at costs. The wayfinder has to make special cognitive efforts to understand and realize these route descriptions. Map reading is known to be a complex task, and maps provide information about a whole area, i.e., far more information than required or expected for a route description. Metric information is difficult to realize for a human and has issues with granularity. Views and virtual reality animations are different from the embodied experience of the wayfinder in perspective, detail, light and street life. Thus it has an advantage when people sketch routes verbally or graphically, concentrating on essential and relevant route properties and relations to the environment. Grice's conversational maxim of relevance comes into play (Grice 1989), and Frank has shown that from the perspective of pragmatics longer route descriptions are not necessarily leading to better wayfinding processes (Frank 2003).

Last, but not least it is advantageous when people communicate routes by referring to cognitively salient features or properties, in contrast to references to travel network segments and nodes, the navigation services' primary data resource (Denis et al. 2007; Klippel et al. 2009; Tenbrink and Winter 2009). Route descriptions from people are more memorizable and typically shorter.

In summary here is an argument that people are superior to computers in (in principle being able to) choosing more *appropriate* routes as well as choosing more appropriate route descriptions. Even more, they do this relatively effortlessly, and we are far from knowing how to tell the computer to replicate such skills. While we argue here by principle, it is not claimed that any human route description is per se more appropriate. People can choose routes or route descriptions that fail, that are far from any optimum, or that are ambiguous.

If we agree that human spatial communication behavior is intelligent, then it is desirable to design navigation services capable of such intelligent spatial communication behavior. Accordingly, one final question has to be answered: Can a computer ever successfully imitate a person?

Crockett (1994) approaches this problem referring to the frame problem. The frame problem is the problem, given a dynamic world, of how to limit axiom revisions in logical systems (McCarthy and Hayes 1969), or more generally of how to limit the updates of beliefs about the world given that the world changes or we interact with the world (Pylyshyn 1987). Assuming that a system knows the states of the world at a time t_0, then at time t_1 changes have occurred. Some of them may be known to the system and can be introduced by axiom revision, but what about the other states? The frame problem is especially relevant in a dynamic domain such as wayfinding. For example, when agents have moved, their location can be updated. But at the same time the state of mind of the agents may have changed, the state of the traveling network may have changed, and costs of traveling may have changed.

Crockett points out that a computer, to pass the Turing test, has first to solve the frame problem. He argues that, since a solution of the frame problem is not in sight, the answer to this final question is negative: a computer most likely will never successfully imitate a person. All this can only mean that a requirements analysis for an intelligent navigation service is always tentative. An intelligent navigation service can only be approximated. Ideas to design such a spatial Turing test are laid out elsewhere (Winter 2009).

3 A Framework for the Requirements Analysis

In this section a systematic framework to study the desired characteristics of an intelligent navigation service is developed. We will concentrate on wayfinding scenarios; accordingly the subsections will combine three independent approaches to wayfinding communication. One is about the phases of wayfinding communication and the individual tasks of the communication partners during these phases. The second is about the spatio-temporal context of wayfinding communication, and the extent to which it is considered by the communication partners. The third approach is about the characteristics of an intelligent autonomous agent to be able to imitate their communication behavior.

3.1 The Phases of Wayfinding Communication and Their Tasks

Klein (1982) and Wunderlich and Reinelt (1982) have identified four phases in the human wayfinding communication process:

1. the *initial phase*: a wayfinder asks an informant for directions,
2. the *center phase*: the informant provides route directions,
3. the *securing phase*: either the wayfinder or the informant want to make sure that the wayfinder has understood the given route directions, and
4. the *closing phase* of closure and separation.

Nearly all research so far focuses on the center phase, studying either route directions provided by people (e.g., Klein 1979; Denis 1997), or studying how route directions can be generated automatically (e.g., Dale et al. 2005; Richter 2008). This is the only necessary phase; the other ones are optional. An extreme example might be the printed travel guide, providing a route description to the reader without a specification of a request by the reader, without a securing phase, and without a closing phase other than that the reader closes the guide book or turns the page, i.e., averts his attention.

At each stage of the communication Klein (1982) as well as Wunderlich and Reinelt (1982, p 183) identify three subtasks present:

1. a *cognitive* task (e.g., activating a spatial cognitive representation);
2. an *interactional* task (e.g., initiating and terminating the verbal exchange, or providing a route description);
3. a *linguistic* task (e.g., expressing a comprehensible route description).

Interaction between the cognitive and the interactional task, in the context of a machine as informant, includes not only the cognitive abilities of the wayfinder, but also the internal data models and algorithms of the navigation service. Between these tasks the focus is on identifying and modeling the references that have to be conveyed and understood (the content). The third task focuses on their actual representation in a specific sign system (the language). Wayfinding communication can use multiple sign systems (verbal, gesture, graphics), which may all very between different cultures.

3.1.1 The Initial Phase

In the initial phase the wayfinder has the lead role and talks to the route service. According to Klein (1982, p 168), the initial phase consists of three subtasks for the wayfinder:

- getting into contact with the informant;
- making clear what he wants;
- succeeding in getting the informant to take over the task of giving him route directions.

Neither Klein nor Wunderlich and Reinelt (p 183) went on to study the initial phase in detail. However, we identify the three subtasks:

- A cognitive task. The wayfinder has to find a proper specification for his route request, which means a specification based on their own spatial cognitive representation that is sufficient for the informant in the given communication context. Vice versa, informants have to activate their spatial cognitive representation to identify the specification of the wayfinder.
- An interactional task. The wayfinder has to manage to get into contact, to specify a route, and to convey his request. The informant has to pay attention, listen, and respond by confirming that the specification of the route was received and sufficient.
- A linguistic task. Wayfinder and informant interact via sign systems, and all three subtasks of the initial phase have to be (a) expressed in one of these sign systems and (b) understood by the recipient. The wayfinder has to be ensured via signs that the informant took over.

An example for the initial communication phase with a navigation system, a web-based public transport planner (Einert 2006), is shown in Fig. 1. A more thorough discussion of this example can be found elsewhere (Winter and Wu 2008).

3.1.2 The Center Phase

The phase of giving route directions is initiated and terminated by the informant (Wunderlich and Reinelt, 1982, p 187). In this phase again we can identify:

- A cognitive task. The informant – e.g., the navigation service – has to interpret correctly the specification of a route request by the wayfinder.
- An interactional task. The informant has to plan a route according to the specification.
- A linguistic task. The informant has to express the route in a comprehensible manner, verbally and/or graphically.

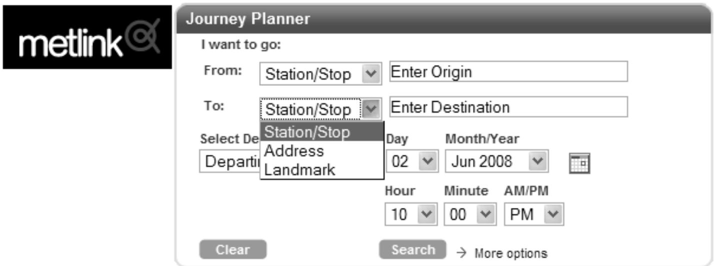

Fig. 1. The initial communication phase with Metlink's Journey Planner (snapshot from June 2008, © Metlink).

Fig. 2 shows a route description of the web-based public transport planner of Fig. 1. A more thorough discussion of the cognitive, interactional and linguistic tasks of this kind of route descriptions can be found elsewhere (Tenbrink and Winter 2009).

Travel by		Time	Details	Map	Information
	DEP:	Sun, 10:58 am	**From Stop** 11-University of Melbourne/Royal Pde (Parkville)	STOP MAP	
			Take the Route **19 tram towards City (Elizabeth/Flinders St)**		Time 13 min Frequency: 6 min Zone(s): CitySaver Operator: Yarra Trams Leg Timetable
	ARR:	Sun, 11:11 am	Get off at stop 1-Flinders Street Railway Station/Elizabeth St (Melbourne City)	STOP MAP	

MODIFY | SEARCH AGAIN | RETURN JOURNEY | ONWARD JOURNEY

Fig. 2. Route directions given by Metlink's Journey Planner, upon a request for a trip from *University / Royal Parade* (a stop name) to *Flinders Street Railway Station* (a stop name) departing earliest at *10:50am* on *27 July 2008* (© Metlink).

3.1.3 The Securing Phase

Wunderlich and Reinelt (1982) report a large variety of communication patterns in the securing phase between people. They can consist for example of summaries, repeats, paraphrases, more detailed descriptions of crucial parts, additional information for the decisions points along the route, or a discussion of alternatives. Corresponding to this diversity we identify a variety of cognitive, interactional and linguistic tasks, some of them assigned to the wayfinder, some to the informant. However, they basically repeat the initial and center phase: expression of a question, understanding, acting on a response (e.g., modifying, generalizing or precisifying the plan), and conveying the response.

Aspects of a securing phase are present in Fig. 2. A wayfinder can click on the hyperlinks in the verbal route descriptions to get more information on the stops, and also stop maps and leg timetables can be requested. Further buttons provide options for re-enquiry (*Modify*, *Search again*, *Return journey* and *Onward journey*). The securing phase is terminated as soon as the wayfinder initiates the closing phase.

3.1.4 The Closing Phase

As Wunderlich and Reinelt (1982) remark, "only . can state that the request has been satisfactorily fulfilled" (p 188). A typical initiation of the closing phase is an expression of gratitude, and termination is made by turning away. In this phase we can identify:

- A cognitive task. The wayfinder determines that he is satisfied with the given information.
- An interactional task. While the wayfinder's attention moves to realize the given information, the informant can deactivate his cognitive map and return to conventional communication or other tasks.
- A linguistic task. The wayfinder should indicate that he is satisfied.

Our example of the web-based public transport planner gives the wayfinder the opportunity for giving feedback, as an expression of gratitude, and for printing the directions (also indicating satisfaction). Further a wayfinder can follow some links to external webpages, or they can simply close the web client and turn away from the machine, be it a mobile device, a terminal, or a desktop computer.

3.2 The Spatiotemporal Context of Wayfinding Communication

Communication with a navigation service takes place in a spatiotemporal context. To capture and categorize this context let us refer to Janelle

(2004), who studied spatial and temporal communication constraints between communication partners given the diverse range of communication channels. His categories concern (see also Table 1):

- location of the communicators: *physical co-presence* or *telepresence*
- time of the communication: *synchronous* or *asynchronous*

Compared to Janelle's two dimensions for a general communication context, a wayfinding communication is coming with two other context dimensions (called indexes or deixis in pragmatics, see Suchman 1987):

- location of departure: *from here* or *from elsewhere*
- time of departure: *now* or *in future*

Table 1. Janelle's spatial and temporal communication constraints (2004) applied on seeking route advice.

	synchronous	asynchronous
physical co-presence	e.g., face-to-face, or from mobile location-aware device	e.g., from you-are-here maps, or departure plans at bus stops
telepresence	e.g., via telephone or from web service	e.g., departure plan from a web page

With this categorization at hand, one can distinguish the communication context for different navigation services. For example, services on mobile devices – such as location-based services, car navigation services, or tourist guides – establish a context characterized by the quadruple {*physical co-presence*, *synchronous communication*, *from here*, *now*}. They can infer the meaning of *from here* by mobile positioning. In comparison, services provided on the web for in-advance trip planning establish a context characterized by the quadruple {*telepresence*, (quasi-) *synchronous communication*, *from anywhere*, *anytime*}. Especially web-based navigation services have no clue to distinguish between wayfinders seeking advice for immediate departure, i.e., from their current location, and wayfinders seeking advice for any time in the future, i.e., from possibly another than their current location. Nevertheless, web-based navigation services typically pre-fill the departure time with the actual time as a default (Fig. 1). They do not yet use positioning technologies to pre-fill the departure location.

3.3 Representing an Intelligent Agent in Wayfinding Communication

A service has to understand a person's wayfinding request and has to respond as another person would do. This was called intelligent communication behavior. For artificial intelligence Brooks (1991) has identified three characteristics of an intelligent agent: being able to cope with situatedness, embodiment and emergence. To be precise, Brooks lists a fourth property, intelligence. For him, intelligence shows in the complexity of behavior "determined by the dynamics of interaction with the world" (p 584). In the present paper, however, the intelligent agent – the navigation service – is not itself physically autonomous in the world, but communicates to an agent that is situated, embodied and capable to cope with emergence: the wayfinder. Furthermore, the service is supposed to communicate like a person, who has all these abilities. Accordingly, in our case intelligence does not appear in the complexity of any physical behavior of the service, but in the complexity of its communication behavior. This means the service requires an awareness of situatedness, embodiment and emergence to be able to give route advice like a person. This argument is still in line with Brooks's (1991) argument for a bottom-up emergence of intelligent behavior. It is also in line with current human computer interaction paradigms. For example, Dourish (2001) – "dialog is central to our notion of interaction with the computer" (p 10) – identifies embodiment as the common ground and challenge for human computer interaction (p 22).

Hence, an intelligent navigation service's communication behavior should be:

- Situated. It should be aware of the context of the communication situation. Beyond the spatiotemporal context discussed above (section 4), this includes perception and an awareness of the environment of the current location of the wayfinder, and what it offers and affords. Our example (Fig. 1 and 2) is poor of situatedness except the pre-fill of departure time.
- Embodied. It should be aware of the human capabilities to move in an environment, and their commonsense, or naive understanding of the world (Egenhofer and Mark 1995). The particular person and its abilities and preferences can be taken into account. With respect to content of advice, this concerns concepts of mobility such as comfort or convenience, costs, risk or trust. And with respect to language, this concerns proficiency in relative, qualitative and egocentric spatial concepts, which also enable to uncertainty. Our example (Fig. 1 and 2) is tuned for public transport users, but not flexible enough to adapt to other means of transport or more specialized individual requirements.
- Aware of emergence. It should be aware of the coherent cognitive structures of the wayfinder that have evolved during the process of learning spatial environments. This concerns their procedural and declarative spatial knowledge, in particular the hierarchic organization of spatial cognitive representations. Our example (Fig. 1 and 2) does not show any

consideration of previous knowledge of the wayfinder, but it has a hierarchic approach of releasing more details on request.

4 Conclusions

This paper suggests a criterion for intelligent navigation services: a Turing test of limited scope and tenor. The test is limited to the domain of giving route advice, and limited to the tenor of a natural wayfinding discourse. In accordance with the original Turing test, the communication channel may still be teletype (text, such as in web forms for the wayfinder, and in verbal descriptions by the web service), but a variety of other channels exists as well, such as speech, graphical interfaces, and visual interfaces to cope with facial expressions and gestures. A navigation service will pass this test if it behaves in its spatial communication like a person. This criterion forms a vision and also a benchmark for the directions of further technological developments in this area (Winter 2009).

Since this criterion requires imitating human communication behavior, it is then used as a motivation to study the desired characteristics of an intelligent spatial communication. A framework is presented of characteristics derived from combining three independent approaches to study the human wayfinding communication process: the phases of wayfinding communication, the spatiotemporal context of wayfinding communication, and the characteristics of an intelligent autonomous agent. Since these approaches are sufficiently orthogonal they can be intersected. Fig. 3 illustrates this for two of the three approaches, communication phases and tasks in each phase (section 3.1) and situation awareness (section 3.3); spatiotemporal context (section 3.2) forms the fourth dimension.

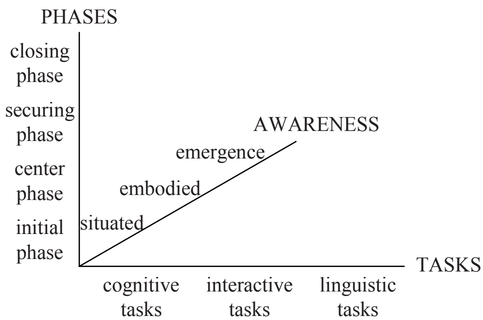

Fig. 3. The framework built by the phases of wayfinding communication with their individual subtasks, crossed with the properties of an intelligent agent. Missing in this graph: the spatiotemporal context, forming a fourth dimension.

From the discussion in section 2 we can conclude that any framework is insufficient to facilitate designing a service guaranteed to pass the test to be called intelligent. Nevertheless, in our framework we could find reasons for each approach to be included in a benchmark, among them their orthogonality.

The four dimensions of this framework have already shown to be useful in a first investigation of the initial phase of the communication process identifying requirements and needs for further research (Winter and Wu 2008). It is expected that in the future the framework can be used to study systematically the structure of existing knowledge, gaps of knowledge, and requirements for research of the other phases as well. Also existing navigation services can be investigated by this way.

Acknowledgements

This work is supported under the Australian Research Council's Discovery Projects funding scheme (project number 0878119). Anonymous reviewers gave valuable comments on an earlier version of this paper.

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