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Cognitive traveling in digital space: from keyword search through exploratory information seeking

Vision Article

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Abstract: This paper surveys principal concepts involved in various approaches to web search. There are many attempts to improve key word search. There is the concept of exploratory search, which represents a shift towards more complex view of the interested fellow's role, widening her options. We propose a more radical shift towards viewing information seeking as cognitive traveling in the digital information space involving both web and digital libraries.

Keywords: keyword search • exploratory search • cognitive traveling • social web • semantic web • digital space • digital library • interested fellow

1. Introduction

Keyword search is a standard approach to information retrieval that has been used for a long time in a pre-web age. It is therefore not surprising that this scheme has been adopted by search engines operating on the web. It should be noted, however, that other approaches, e.g. one based on categorization, are attempted, too, but still keyword search is undoubtedly currently the dominant metaphor. After inception of the web it took some time to realize (at least some of) its potential. There was a growing realization that web could be, and gradually has been becoming, an immense well of information. Soon people were caught by surprise by the speed of growth and its apparent sustainability. It has been quite common (including myself) to write articles starting motivation with expressive statements that everything is on the web nowadays, implicitly including also the interpretation that what is not on the web is as good as nonexistent so the closed world assumption holds for the web.

Things are more complicated. If the window to see contents of the web is the standard search engine interface that involves both preprocessing of the query and then postprocessing of the results, then our view of the web is limited by the capabilities of this interface and the underlying search engine. It is known that not all the contents of the web is indexed by search engines, but indexing is a precondition to be retrievable. There are vast areas of the web that are

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not retrievable, cf. the notions of shallow and deep web. There is also another temporal reason since indexing is always behind in time to occurrence of new content in a web page, so for some initial period of time even information in the shallow web that is retrievable under standard circumstances is not visible.
Besides these principal space and time limitations of ability to be retrieved there are other grounds for suboptimal performance of information search in the web, be it expressed in terms of precision, recall or some other measure. This is one of the hottest topics of research today. For general research public, improving the actual search engine is not a straightforwardly open topic of research due to proprietary nature of the most popular search engines which are mainly researched, designed and amended by their competing owners. It is therefore left to orient most of its creative talents to interface, including both preprocessing and postprocessing in the above suggested sense.
We mention some of the research endeavours in both these areas. However, despite many interesting results of research that have led to improvements, such approaches are somehow limited. Besides the effective exclusion of search engines, we argue that the view as outlined above is too narrow. Information seeking should be viewed in a much broader sense, not as a (whatever sophistically) preprocessed and postprocessed keyword search. In recent years, the notion of exploratory search has attracted much attention as an alternative to the standard keyword search. However, we shall show that it is much more a complement and an advancement of the standard approach. Finally, we outline some possible directions beyond these approaches. In particular, we present our idea to view information seeking as traveling in digital space.

2. Preprocessing

In a sense, preprocessing, i.e. some kind of preparation of the input data to be subsequently processed by a search engine is more important than any manipulation that occurs afterwards. Let us bear in mind that ultimately, output is determined in a significant extent by input. If something is misplaced in the modified list of keywords, which is input to the search engine, it will determine its output for better or worse. Any improvements of output then are just attempts to amend results that are inherently limited by input imperfection. Therefore, much emphasis has been placed in research on ways how to prepare input to the search engine.
One direction of research is query expansion. Original query is expanded to increase chances that the search engine will return results that better reflect the expectation or intention of the interested fellow. What are possible sources that are basis for expansion? And which of them are most effective to achieve improvement in information seeking? There are several approaches to investigating these issues.
One idea is to augment the query with some additional information that reflects interested fellow's intention. For example, key words such as java or apple in a query can mean very different things depending on if the interested fellow is interested in geography or programming, computers or pomology. If we want to have scope of possible interpretations of the query narrowed but do not want to be dependent on receiving any further information from the interested fellow, we may take previous searches to extract from it clues pointing at interested fellow's intentions. Query logs can be analysed so that interested fellow's intention is automatically identified [30]. Another possible source is the personal collection of text documents, emails, cached web pages, etc. constituting her desktop or Personal Information Repository [25].
There are works favouring explicit interested fellow's feedback with the obvious weakness in dependency from the interested fellow. Luckily, interested fellow leaves often some implicit feedback [69, 77]. Of course, all such approaches attempt to contribute to personalization of search. But is personalization of search necessary? Many queries are such that almost everyone who issues them has the same thing in mind and seeks the same information. In such cases, no personalization is necessary, at least during preprocessing. There are many other kinds of queries, however, which mean different thing to different people. Even if two different interested fellows write the same query they are interested in different information. There is an ambiguity in a query. It can be analyzed and modeled. This can help identify where a query can benefit from personalization [78]. Several important user personalization approaches and techniques developed for the web search domain are presented in [54]. A simple personalization layer that improves relevancy of search was proposed in [40].
One of the approaches towards an automatic personalization of web search is proposed in [24]. They make use of PC desktop, which is source of a wealth of specific information. Having extracted it, it allows for an increased quality of user profiling. More specifically, they select personalized query expansion terms for web search using three different desktop oriented approaches: summarizing the entire desktop data, summarizing only the desktop documents relevant

to each user query, and applying natural language processing techniques to extract dispersive lexical compounds from relevant desktop resources. Related issue supportive to these approaches is text mining [22, 31, 61, 66].
A novel query expansion algorithm is proposed in [89]. It acts as preprocessing set up on the client machine. It can learn an interested fellow's preference implicitly and then generate a profile of the interested fellow automatically. When the interested fellow inputs query keywords, more personalized expansion words are generated by their algorithm. These words together with the query keywords are then submitted to a popular search engine.
A related but somewhat different approach from the interested fellow's point of view is assisted query formulation. The interested fellow is assisted right after having formulated first piece of text expressing her interest. In a series of steps: query formulation – find – re-formulation, the text (search query) is becoming finer and more accurate [29].
As a further step in the level of assistance, query suggestion is another area of research. It is most widely known for popular queries but the usual experience shows a sharp deterioration for less frequent ones. To improve rare query suggestion, other sources of information are sought to leverage implicit feedback from interested fellows in the query logs. In [71], a combination of interested fellow's click and skip (of the returned URL's) information is used as an implicit feedback.

3. Context

In approaches using personalization, there is quite often mentioned context as another important concept. It shows its meaning immediately: (*con* – with) *text*, hinting at the surrounding situation for interpretation of the text. Context can be thought of as all the circumstances, the data and information that are somehow relevant to the event or fact. For the purpose of the particular research that we overview here, this definition is too vague. A very eleborated and formalized model of context has been proposed by [33]. They propose a context model distinguishing three distinct layers: knowledge layer, state layer, contextualization layer and, in addition, they add a fourth layer describing context-based adaptation. There are following components needed for this conceptual context model:
(a) Information about the current situation/state provided by sensing components
(mapping internal and external information sources into state objects).
(b) Background information about the (application) domain.
(c) Contextualization rules to constitute a contextualized state.
(d) Adaptation rules that define a set of meaningful adaptations according to the contextualized state.
In relation to web search, Lawrence [48] describes the context of a query as for example, the education, interests, and previous experience of a user, along with information about the current request.
Several approaches have been taken to using context in web search [43, 56, 57]. Among them, query rewriting, iterative filtering meta-search and rank biasing seem to be dominant. Query rewriting is based on appending keywords form context to search query as a string and submitting the augmented query to standard search engine.
Iterative-filtering meta-search does not augment a query but rather generates many different sub-queries and submits them to several search engines. Upon receiving results, it re-ranks them and aggregates into one set. Rank biasing supposes that a query and context of keywords are sent to modified search engine as a complex query. Having received documents matching query it then re-ranks them by fitness to context. More generally, query preprocessing opens room for context to be a source for query augmentation. A query is seen as a short list of keywords. To rewrite it, we have to identify additional keywords.
The concept of context is quite general and, as we noted earlier, often a loosely defined one. Interested fellow's interests, past searching experience etc. can be considered part of it. There are also other views, concentrating more on query itself [6]. Still other approaches employ collaboration of interested fellows [84]. There are also investigated completely different forms of search that require specialized user interface (e.g. facet browsers [44] or one-page search engines).
In a sense, web search adjusted in one way or another to a context as determined by the interested fellow is a personalized search. The other way round, when the interested fellow possesses a personal profile represented in a processable way, e.g. in form of ontology, an ample room opens for personalized web search, too [70]. Our point is, however, that there is a room for improving results of web search even if no concepts of semantic web are employed. It is possible to expand a query in a quite complex way based on personal information [25].

4. Postprocessing

Personalization and context information are two major sources of information that can be used not only in the preprocessing phase.
After a usual search engine returns a list of results, there are several ways how to proceed. The list can be modified to better reflect personal preferences of the interested fellow. Or the list can be adjusted to the context of the search. These both can be viewed as examples of postprocessing. Besides these and possibly other ways of postprocessing, there is another important role for this phase: to gather additional information that will enable better preprocessing in the next round.
An important area of research is to investigate ways of re-ranking results. In [63], interested fellow's browsing behaviour is source for data mining frequent access patterns. In accordance with her interests mined and feedbacks acquired, they propose Personalized PageRank for dynamically adjusting the ranking scores of web pages.
There are attempts to employ semantics description languages for representation of interested fellows' profiles. In [26], there is described a personalized search approach involving a semantic graph-based interested fellow's profile issued from ontology. Interested fellow's profile refers to her interest in a specific search session. It is built using a score propagation that activates a set of semantically related concepts and maintained in the same search session using a graph-based merging scheme. Personalization is achieved by re-ranking the search results of related queries using the user profile.
A possible approach to augmenting an individual interested fellow's profile is by using data from other interested fellows. In [78], the authors studied whether groups of people can be used to improve relevancy, or in general quality of search. They explore the similarity of query selection, desktop information, and explicit relevance judgments across people grouped in different ways. As could be expected, some groupings provide valuable insight into what members consider relevant to queries related to the group focus. On the other hand, it can be difficult to identify valuable groups implicitly.

5. Exploratory search

Conventional approaches to targeted search suggest that the interested fellow knows what she is looking for and formulates a search query by using keywords for search engine. The main problems in current approaches are limited opportunities of query construction using keywords, search query ambiguity, and the minimum support for query modification and results viewing, and the fact that interested fellows often cannot say in advance what they are looking for [38]. We unwittingly just guess those keywords that might be found on pages with information that we want to obtain, with sufficient relevance that it will be placed at top positions of the list of search results. In targeted search, search engines improve the search success especially by complementing or reformulating the queries or by reordering the results. Among more sophisticated approaches belong e.g. support of query disambiguation [17] or advanced search using clustering [18].
Problem formulation of the initial query for a search engine when the interested fellow does not know precisely how to specify the search target is addressed by the exploratory search approaches [51], e.g. by search based on the views across facet browsers mSpace, RelationBrowser++, by search using the examples in the IGroup [85], by support of query modification or by advanced methods of search results browsing in VisGets [28].

6. Social aspects

Originally, a website was only a content provider. Gradually the purpose of a web site changes and a web browser becomes a gateway to a variety of platforms and information channels. Web 2.0 has given interested fellows an ability to actively participate in the creation and organization of the web. It has also become another place where an important role is played by communities – those that are based on real-world social relations, as well as those which are purely virtual and created by ad-hoc grouping of similarly behaving interested fellows [9, 23, 30]. Search, which relies on the links between interested fellows, can efficiently tackle the problem of query disambiguation, can reorder the search results or can add to the query special community annotations [10].
Current research in the field of search and recommendations has been refocusing more on the usage of the user in-

teractions in order to enrich the searched information space, which allows the search refinement [8]. These methods include the use of annotations in the context of social relations [7], temporal properties of interaction with objects and information sources, explicit and implicit evaluations of objects by users [39], the automatic derivation of hierarchical and overlaying categorizations [68] and the use of highly domain-specific characteristics (e.g. geographical distance or spacial data [27]).

Semantic web is based on the concept of ontology and a lot or research has been going on, including [11, 21, 34]. Searching the semantic web has been investigated [57], including various forms of semantic search [32] or recommendation [76]. Social navigation is also one of the relevant issues [52]. When considering social aspects, it is also important to note the potential of collaboration for effective information retrieval [3].

Another interesting concept emerges described loosely as collective wisdom or wisdom of crowds. One way is to use the knowledge that users "encode" in folksonomies, for example in social tagging. With sufficient number of users and marked resources they begin to form genuine relationships between brands, resources and users [55].

In almost any approach to web search, there arises the question how to model the interested fellow and her context. Traditional approaches to interested fellow modeling (a.k.a. user modeling) are not appropriate in the case of web and digital libraries as they do not count with the large and dynamic information space. The solution is to come out from so-called open corpus approach [20] which is based on a two-level model of the interested fellow (document level and conceptual level). Effective combination appears to be based on tags, keywords and more complex formal models which allow covering various dimensions of the interested fellow [35]. Many other works include e.g., [1, 16].

Both targeted and exploratory search are directly related to the effective visualization of search results overview and then the results themselves (documents, pages, information). Current approaches in the exploratory search, in addition to traditional tabular display of search results, make a significant focus on supporting the process of searching through faceted browsers like mSpace [88], RB or OntoViews [50], on improving the user orientation and understanding of information using link or content annotations.

Essential is also the support for creation of visual search queries by using approaches based on views, visualization of search and browsing history [53] with graphs and interactive visualization of relationships between search results using (hierarchical) graphs [67]. Advanced visualization approaches involve information preprocessing using clustering, for example in the search engine clusty.com, concept analysis, or reasoning context. In the area of semantic web, Tabulator [13] addresses linking of several visualization approaches using nested charts and maps. Support is still limited to individual domains, often with a manually created metadata, and without taking the dynamics into account.

7. Cognitive traveling in digital space

Finally, let us outline some possible future directions of fundamental research in area of information retrieval based on search in large information spaces. Interested fellow receives or derives information in the process of her interaction within the information environment including friends and people with similar interests. Cognitive metaphor of traveling in the digital space describes an interested (often curious) fellow who travels in the web or visits digital libraries, sometimes purposefully, sometimes even without a specific objective, in order to obtain interesting information to augment her knowledge or learn something new [77] or just have fun. The range of possible cognitive experience is not limited.

By describing the interested fellow's endeavour as traveling we suggest that acquiring some information from the digital space as we experience it now is not a single act, but rather a process. It may involve several steps. But this is not surprising. Several steps may be necessary in order to improve the quality of the acquired knowledge beyond results from a "standard" search.

Traveling in general usually requires some kind of navigation. Traveling in digital space can make much use of navigation. It can be based on signs and officially provided information, or it can be based on observing and imitating others, or there can be investigated other ways.

Interested fellows leave traces in the digital space, sometimes even without being aware of it. For example: evaluations, recommendations, annotations, inscriptions on a virtual wall [45, 46]. Interested fellows communicate with others, forming communities of those sharing interests. They express their views, write emails, blogs or microblogs [47]. Even a track record of a journey in the digital space is important information, especially if complemented with knowledge of how successful this traveling was.

All this is potentially applicable in order to improve the cognitive structure of semantics for interested fellows as

information seekers (consumers), or digital space travelers. The potential of digital libraries is waiting for the revelation particularly through their integration, stressing the importance of interested fellow's information behaviour [72, 73]. The web can provide distributed space for the unification of meaning across different libraries [74]. The space, with its information seeking inhabitants, forms a world, which has ecological dimensions worth studying [75]. Forward-looking "single" digital world of information resources can use advanced search features, personalization, social networking, or context consideration.

In such an environment it is important to consider methods of presentation and visualization of information, in particular of a response to the query. A very promising method seems to be multi-paradigm visualization, where depending on the presented information and the state of the process of searching, the most appropriate form according to the nature of retrieval and context (facet browsing, graphs, visualization, creation of clusters and conceptual models, specific browser content) is selected [82, 83].

So far, the known search methods do not provide sufficiently precise results and results sufficiently covering the relevant subspace (cf. precision, recall). This is largely a consequence of the way how people use the search engines - what queries they submit. Moreover, the amount of information on the web increases rapidly. Therefore there is a permanent demand to improve methods for searching and accessing information. Nowadays, unstructured text is still the prevailing form of storing data in the web. Such a method of content storing does not support automatic processing. There are several research directions that focus on accessing of the web content using various engines and tools in order to enable automatic processing of the content (the semantic web). However, the results have a limited scope for specific domains and specific applications.

Development in this area matures to the point where the web is becoming so important and at the same time still unknown phenomenon that some identify it as a separate, original object of investigation. There are even initiatives to establish web science [36] as a new scientific discipline.

We formulate a working metaphor of cognitive traveling in digital information space, covering web and digital libraries. The concept of digital (information) space is a useful abstraction, because any activity in space is usually associated with some movement and moving in space can be seen as traveling. Even those interested fellows, who know what they are looking for, can find themselves in a situation that before they find what they originally have been seeking, they encounter an interesting link or information and unconsciously start searching in a new direction albeit with less accurate search target. However, there are also such interested fellows who do not know exactly what they want, but they like wandering in the information space, leaving navigation to immediate evaluation of interestingness of what they see or read.

8. Related and future work

There have been attempts to go beyond the keyword search paradigm even in the pre-web age. Bates [12] introduced the berrypicking approach to information seeking, see Fig. 1.

The approach can be viewed as a precursor to exploratory search. By encountering new information in the currently read document (by eating the recently found and picked berry) the interested fellow gets new ideas and directions to follow, and also new conception of the query.

Obviously, the outlined view of traveling in digital information space is just one of several views presented or emerging. A very comprehensive view of interactive information retrieval is presented in [31], see Fig. 2.

The actual search process, involving request, query, its matching in documents etc. is the immediate information retrieval context. Around this seeking process is the seeking context that encompasses formulating a seeking task and evaluating the seeking result. Another layer around this is formed by the work task context, and all this takes place within a given socio-organizational and cultural context.

Combining known models of information seeking behavior, a canonical model of social search was presented in [23], see Fig. 3.

There is presented a canonical model of social search structured into three stages: before, during, and after search. According to this model there are externally-motivated searchers and self-motivated ones. Before search, a searcher gathers requirements and formulates their representation iteratively. The actual search can be navigational or transactional or informational. After search, there is search product and searcher can do nothing with it or she can take some action, like organize or distribute the product to proximate or public others.

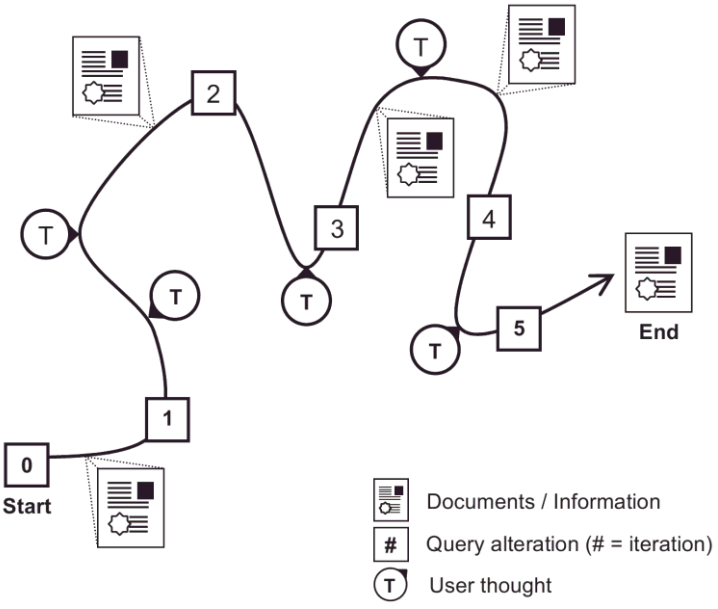

Figure 1. The berrypicking approach (as presented in [87], based on [12]).

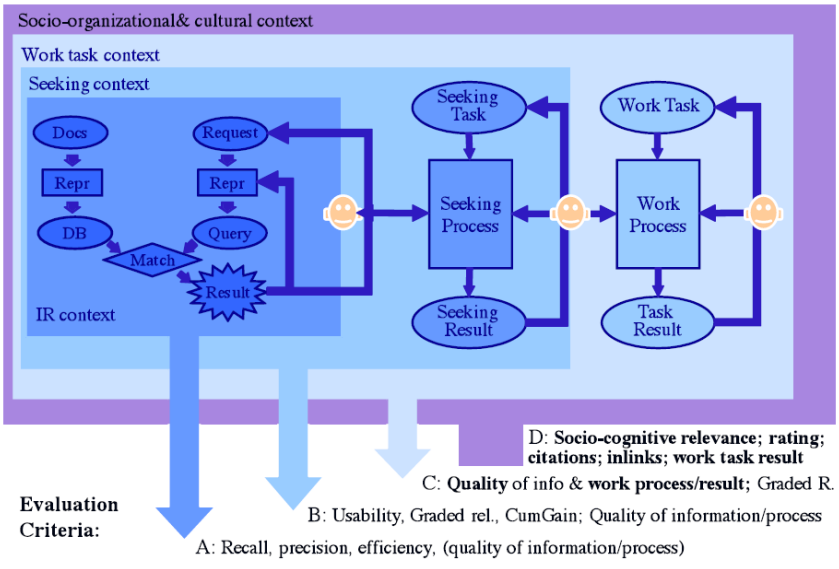

Figure 2. Contextual framework of interactive information retrieval; relevance criteria, from [37].

An interesting view of information-seeking funnel is proposed in [64], see Fig. 4.
The funnel metaphor, to paraphrase its description in this paper, involves wandering, exploring, seeking and asking. When wandering, the interested fellow does not have an information seeking goal in mind, but she may have a meta-goal. An example could be "suggest a theme of my dissertation thesis". When exploring, the interested fellow has some general goal, but does not have a plan how to achieve it. An example could be "learn about the origin of algorithms". When seeking, the interested fellow already begins to identify her information needs, initially open-ended but gradually narrowing them. An example could be "find out about the role of transistor in electronics". Finally, when asking, the interested fellow has a very specific information need. The information need can be expressed by a simple question,

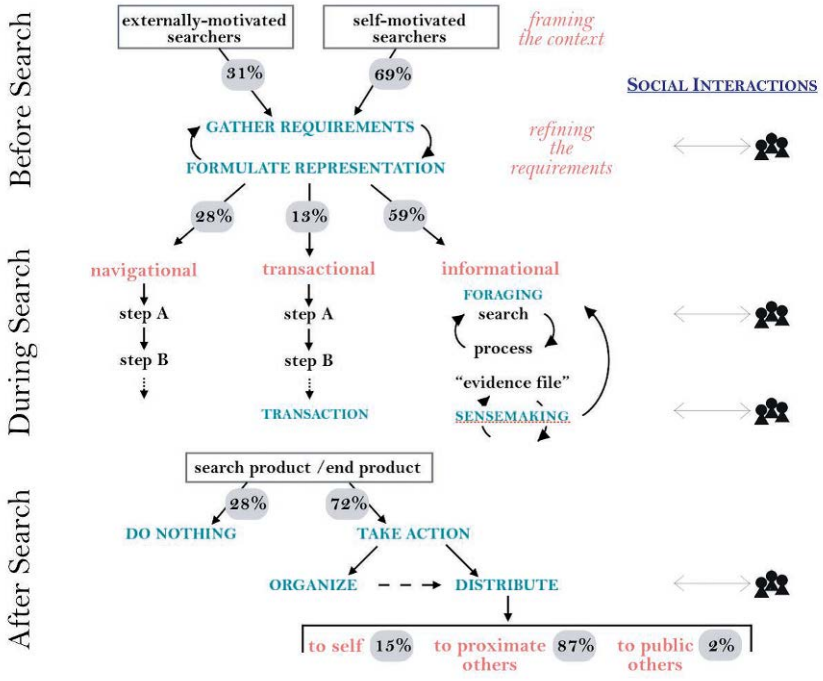

Figure 3. Canonical model of social search, from [23].

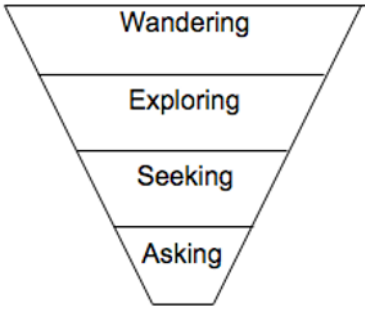

Figure 4. The information seeking funnel, from [64].

such as "when was the transistor invented?". The metaphor nicely corresponds to our vision. It explicitly identifies wandering as the information seeking activity at the top level. Also, it explicitly acknowledges the role of exploring. The identification of the asking a question level is very important, too. Indeed, queries expressed by a composition of key words are always just more or less imperfect substitutes of a straightforward question, as we would put it in a natural communication.

Undoubtedly, there is much need for future work in this area. There are many possible paths to follow. We offer a new metaphor of traveling. It takes place in a digital space. It is both social and personalized. It foresees a cognitive process, not a single act. It offers a framework for searching, or learning, or entertaining.

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