CONTEXT-AWARE SEARCH ARCHITECTURE

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Abstract: There are several reasons for developing a context-aware search interface. In so far, search engines considered the technology perspective – suggesting structural, statistical, syntactical and semantic measures. What is yet missing in Web search processes is the inclusion of the user model. The prevailing situation is a usability hurdle.

While there is a wealth of information about search engines, what is yet lacking is a recommender system. Such as could be provided by a set of adequate principles and techniques, as basis for the design of a Web-base interface guiding users towards efficient and effective utilization of the spectrum of search engines available on the Web. The research reported here takes a step towards this goal, suggesting context-aware search architecture (namely, CASA) aiming towards: 1) the analysis of query elements, 2) guiding the process of query modification, and 3) recommending the personalized use of search engines.

A use case illustrates the need for the suggested framework and a prototype Web interface is introduced. We discuss preliminary findings from empirical research conducted with several classes of students in two distinct academic institutes in two different countries, which concerns the feasibility and usefulness of the suggested framework. We conclude with recommendations for further research.

1 INTRODUCTION

The interface level of a Web search process involves three elements: 1) the user's query, 2) a search engine and 3) the search results. Two out of these three elements are anchored in user's context. First is the user's query, which is often subject to negotiation and modification. The query represents the user's model (Marchionini and White, 2007) as it is established by the context of the investigation (Marchionini, 2006). Second are the search results that should respond to the query and reflect its context. Search engines, however, are usually approached independent of the user's context (Kritiquo, 2007; Weinberger, 2009).

This situation, albeit prevailing, is disregarding the opportunities available by search engines' technology which could be proved useful, enhance precision and promote utility for the user – provided they are used in context. This is specifically true for users engaged in *exploratory search* – either as part of business processes or in academic setting (Marchinini, 2006; White and Roth, 2009; White, Kules and Bederson, 2005). The prevailing situation, in which the interface does not allow the selective use of search engines, is a usability hurdle.

What is yet missing is an interface instructing the manipulation between search engines in a manner that considers the user's model – allowing the user a choice between different search engines. For this end the envisioned interface should include tools for user's requirements' elicitation on the one hand, and for the modelling of the user's query within its context, on the other hand.

In order for users to exploit Web search technology, there is a need for tools and techniques that would instruct context-aware utilization of search engines (Vossen and Hagemann, 2007; Weinberger, 2009). Different than the dynamic and active role of the user in the Web 2.0 arena, search interactions remained aloof of the user's individual context. In view of the wide spectrum of search engines (SEs) available on the Web (e.g., popularity-based SEs, social SEs, semantic SEs, hybrid SEs, domain specific SEs) it is surprising that there is no interface instructing search engines' context-aware methodological utilization in a manner that considers the user's query as part of the user's context and with relation to the user's model.

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While there is much research effort aiming to bridge the gap between search engines' methods and the user's model (Martzoukou, 2004; Mammr, ALKhatib, Mostefaoui, Lahkim and Mansoor, 2004), the research reported here takes a slightly different perspective; aiming to bridge the gap between the user's query and the appropriate search engine focusing on the user's perspective, i.e., her context. This research concerns the design of a Context-Aware Search Architecture (namely, CASA) to support a search interface that would facilitate a) an interaction with the user based on b) the user's modified query and c) a search engine recommender system.

Our approach to the design of CASA follows the design science paradigm (Havner, March, Park and Ram, 2004; March and Smith, 1995). Of the research activities outlined by design-science research in IS this paper covers the build (a Web-based recommendation system as part of a search interface) while for the evaluation of this artefact we report on preliminary (qualitative) results of empirical investigation. Of the four design artefacts (i.e., constructs, models, methods, and instantiations), outlined in these frameworks, this research is about a model (i.e., the method instructing the recommender system's principles), which informs a methodology (i.e., the techniques for supporting user's requirements elicitation and query modification processes) and an instantiation (a prototype of the Web interface).

Following this introduction, section 2 holds a brief discussion of search engines. Section 3 describes the need for context-aware search architecture and section 4 describes this architecture, i.e., CASA. Section 5 is focused on the methodology used in this research. We conclude in section 6 with a summary and discussion.

2 SEARCH ENGINES IN CONTEXT

The lack of a consistent methodological approach to Web information seeking research (Baeza-Yates, 2003; Martzoukou, 2004) might be attributed to the dynamic nature of the field. Frequent innovations in search engines' technology modify search engines' classification. Consequently, best practices of the field are often altered (Vossen and Hagemann, 2007). Currently there are several leading practices in search engines technology of which we mention several examples: a) popularity-based SEs (e.g., Google) which also manipulate a host of other algorithms (e.g., statistical measures, Web-genre analysis, clustering and categorization), b) Inclusive-meta SEs (e.g., Myriad, Quintura), c) social SEs that focus on user's contribution (Hakia, FreeBase), d) Semantic Web SEs (e.g., Hakia) and analytic SEs (e.g., WolframAlpha). Other navigation and information retrieval methods follow notions of: Web-genre (e.g., Google scholar), domain (i.e., geospatial), structure (e.g., Wikipedia) or phenomenon such as the long tail of search (e.g., FeedMil).

Taking the HCI perspective, several SEs include features that support user's interaction with the results as obtained, through activities such as providing feedback or by allowing navigation and negotiation of results based on data visualization. Examples are navigation of interactive maps (e.g., Kartoo), user voting (FeedMil), clusters negotiation and categorization (Clusty).

With the advancement of Web 3.0, there are indeed innovative technologies embedded in search technologies (Berners-Lee, Hendler and Lassila, 2001; Finin and Ding, 2006; Ding, Pan, Finin, Joshi, Peng and Kolari, 2005) that assist in incorporating user's annotation (Bao, Wu, Fei, Xue, Su and Yu, 2007) also for the purpose of instructing the user model (Carmagnola, Cena, Cortassa and Gena, 2007).

However, by the most part users are captivated by what could be named: 'the ease of search' syndrome which prevents them from using multiple search engines and the options they suggest. As much as HCI research should approach current practices (Hochheiser and Lazar, 2007) search engines' technology should advance beyond current context building methods such as: a) structural attributes, b) syntactical features, and c) semantic analysis, towards the user's context (Dey, 2001; Kobsa, 2001; Midwinter, 2007; Shen, Tan and Zhai, 2005) in order to reflect on the user's perspective. For this end, users' ought to be considered as actors, allowing them more freedom of action and choice.

Along this lane we mention that classic criteria for information retrieval evaluation are precision and recall. While the prevailing practices will not necessarily promote precision, user's enhanced involvement should not be underestimated as an agent of precision. Against this background a method and a mechanism could be considered, which responds to the bi-dimensional view of the search operation, to include: a) search engines' typology on the one hand, and b) user's query and its context on the other hand. This way search activities

would facilitate an efficient and effective search – in the context of the users' model as represented by her query.

3 THE NEED FOR CONTEXTAWARE SEARCH ARCHITECTURE

This section brings forward the issue of the user perspective motivating this research. A concise discussion paves way to the introduction of a hypothesis concerning the user's perspective. We conclude this section with a use case illustrating the need for context-aware search architecture and explain the relationship between the three elements that constitute the search interaction: the user, the query and the search engine.

3.1 The User Perspective

Of the two most common tasks which best represent Web HCI, users' contribution to online communities is mentioned alongside search processes. For the former, Preece and Shneiderman (2009) identified several distinct types of users participating in online communities. Their work illustrates a typology that is based on the classification of user's contribution – based on users' task and role, identifying three user types: a reader, a contributor and a leader. Similar to this user's classification, search processes are classified by three search types: a simple search, learning and investigation (Marchionnini, 2006) based on a task-related perspective. Specifically, the tasks considered for user's classification differ by the value assigned to attributes such as the frequency of the iteration, the complexity of the issue at hand, and the context.

In the context of these two typologies, this research assumes value for the contributor and for the leader who are engaged in either learning or investigation. A search that is conducted in this context is likely to motivate users towards the cultivation of adapted search habits that would yield useful results. This assumption might be specifically true in the case of experienced users (i.e., contributors or leaders). This brings us to suggest the research hypothesis that concerns the *user perspective*.

> *Hypothesis 1*: Search operations are mostly conducted using popular search engines while user's navigation between search engines is not a common phenomenon. This is not because search engines are all alike, nor is it because different search engines would not yield different results, but because adequate context-aware recommendation, personalization and adaptation tools for this end are yet missing. *Given the adequate tools, users' search behaviour might be altered*. One possible path would be for the search domain to develop similarities with Web 2.0 tools – where diversions between knowledge sharing tools and online communities are not only acknowledged but are also integrated in services suggested for users and by users' practices.

3.2 An Example use Case

A *user* involved in an *exploratory search* session is facing two challenges that concern the 'how' and the 'where' of the search process: 1) *how* to search refers to several activities related to syntactic and semantic search features such as: choosing key words, query structuring, modification and the identification of the domain and the genre to be explored, 2) *where* to search is about which *search engine* to use. While the latter might appear to be a decision motivated by the technological perspective, there are other relevant perspectives to be included. For instance, we mention the SE's scope and HCI features.

As part of selecting a search engine, the user is required to meet challenges that concern his interests as well as challenges belonging with Web proficiency. While there are a host of interface-embedded syntactical, structural, semantic and statistics features that would support query formulation, there are no interface features directing search engine manipulation. In view of the spectrum of search technologies available on the Web, there is not only much promise that is yet unexploited, but also a serious challenge summoned for the user.

While users might occasionally be aware of the plethora of search technologies, they still need a good reason to use these tools. For instance, a social search engine might yield different results than a popularity-based search engine, since each uses different tracking and indexing methods. As an example, consider the case of a user seeking information about blogging, more specifically: 'how to write a successful blog'. While a popularity-based search engine is likely to return the most popular results, a semantic search engine such as Hakia is likely to return results that origin with user's (recent) input, indicating an innovative guide, tool or

practice. This is not to say that one result is preferable to the other – but to put forward the differences that prevail. In the context of the design of business, research or learning environments, we would like the user – a reader or a contributor, to be aware of her options in a most profound way.

There is in this use case to a) demonstrate the need for context-aware search architecture, b) to describe the relationships between the three elements that are part of a Web-search interaction, and to c) anchor the former two as part of a wider perspective on current HCI challenges.

4 CASA: CONTEXT-AWARE SEARCH ARCHITECTURE

The CASA architecture is comprised of a 1) two-faceted query definition and modification mechanism, and a 2) set of recommendation principles guiding the process of search engine selection. The OSKA-based (Weinberger, 2010) search interface (Web: http://oska-search.info/) is a prototype demonstrating the operation of the framework suggested here. This prototype provides users with an example experience – albeit not fully supported, for a search interaction that utilizes the method presented in this research.

4.1 The Search Interface

A Web-based system demonstrates the method of the CASA-based recommender system. The interface is designed to respond to a) the user's query by suggesting an adequate use of b) a search engine.

For the design of the user interaction (building the query's context) we follow the Ontology for Social Knowledge Applications, namely, OSKA (Weinberger, 2010) intended for aiding users throughout the annotation of Web 2.0-tools user-generated content and context. Since tagging and search are considered the two sides of a coin (White et al., 2005), we assume the ontological construct could be followed for user's requirements elicitation and for query modelling.

The prototype interface (Figure 1) demonstrates the support available for the user in determining the a) query's current focus (i.e., there, *Query type*) and choosing b) an ontological extension (i.e., there, *Question type*). Based on this ontological analysis the system c) recommends the search engine that is likely to yield results that are of highest precision – in accordance with the recommendation principles (described herein).

The mechanism for identifying the Query type responds to the three-perspective view identified for the Ontology for Social Knowledge Applications (i.e., content, task and technology). The mechanism for the identification of the question type follows the WH questions scheme used also in the IS field for the evaluation of information systems.

4.2 Recommendation Principles

This section is dedicated to the five recommendation principles identified for this research. The description of each recommendation principle (RP) is anchored in the context of a search engine type in relation to the WH question (i.e., aspect) for which it best responds. For each search engine type we provide example evidence description, annotated by a-e, followed by a Recommendation Principle, formatted with bullets.

A. Popularity-based Search Engine – e.g., Google: the results tend to spread across several aspects of the query element(s); Answering questions such as: *what*, hence facilitating an introduction to the subject domain. Based on this finding the following RP was formulated:

- RP1: A search for general information that is spreading across several aspects (i.e., responding to WH questions such as 'what'), is likely to be useful by means of using a popularity-based search engine, e.g., Google.

B. A social-semantic search engine, e.g., Hakia: the results tend to focus upon example instances of the query's element(s); Answering questions such as: *what*, *how* and *where*, hence enabling the study of example applications. Based on this finding the following RP was formulated:

- RP2: A search for information describing attributes assigned to a certain concept (i.e., responding to WH questions such as 'what' and 'how'), is likely to be useful by means of using a social-semantic search engine such as Hakia.

C. A Semi-semantic and Visualized Search Engine, e.g., Kartoo, Clusty: the results tend to spread across three instance-level aspects, answering questions such as: *who*, *how* and *where*; facilitating the comprehension of a phenomenon. Based on this finding the following RP was formulated:

- RP3: A search for instance-level responses to questions with relation to a specific domain (i.e., responding to WH questions such as '*who*', '*how*' and '*where*'), is likely to be useful by

means of using a semi-semantic, clustering, visual or interactively enabled search engine such as Kartoo or Clusty.

D. *An Analytic, Semantic-, Social-semantic or Hybrid Search Engine,* e.g., FreeBase, FeedMil: the results tend to focus on several practical aspects, answering questions such as: *where and how, responding to the technology perspective,* hence summoning the user a wealth of information allocated by users to guide the investigation of a subject domain. Based on this finding the following RP was formulated:

- RP4: A search for instance-level information based on user-input (i.e., responding to WH questions such as '*where*' and '*how'*), is likely to prove useful by means of using an analytic, semantic- and social-semantic or hybrid search engine such as FreeBase or Feedmil.

E. *An Analytic Search Engine*, e.g., WolframAlpha: the results tend to focus on several aspects, presented as a report on the subject of the investigation – based on a dialogue with the user. Specifically this search engine will prove useful for the user facing a depth- and wide-motivated search. Based on this finding the following RP was formulated:

- RP5: A search for a wide perspective perception of a domain is likely to be found useful by means of using an analytic, semantic and hybrid search engine such as WolframAlpha that is empowered by artificial intelligence – amongst other features. This search engine compiles a categorized report of the subject matter, not only introducing the user a host of information in various forms but also allowing him the negotiation and analysis of the presentation of the findings.

4.3 Instructing a User-cantered Search

In this section we illustrate an example use case of utilizing a user search interaction by the method and principles prescribe in CASA using the OSKA-search (Web: http://oska-search.info/) prototype (Figure 1) aforementioned. There are three stages in this interaction. For each stage, the user's role and the system's response are described.

Stage 1 – Search Initialization: user introduces query elements in the search box. For example, the query element may be the expression: blog. The system then identifies the query's dimension (there, query type).

Stage 2 – Query Modification: there are two dimensions to the action lanes defined for this stage. The first concerns the system perspective and the second concerns the user's perspective. The system perspective prescribes two complementary actions and decisions, accordingly. The first concerns the query type and the second concerns the question type. The first would be feasible provided an adequate lexical ontology is available. That would allow the system the automated identification of the query type. Second is the identification of the question type. In this context, the system is designed to respond to three types – responding to 3 ontological dimensions identified in OSKA (Weinberger, 2010): subject (i.e., scope), activity (i.e., task) and media (i.e., technology).

The user's perspective also involves two actions lanes and decisions, accordingly. First, the user has to choose a *question type* following which the system suggests to him an extension aspect. For instance, if the query includes a term such as 'blog' that it is identified (i.e., by the system) as 'subject'; consequently, a corresponding WH questions (there, question type) are suggested (Web: http://oska-search.info/) to further focus the query. For instance, suggesting the 'how' or the 'where' extensions. This procedure is an example for a user's requirements elicitation process that is followed by a corresponding query modification process provided by the system's part.

Stage 3 – adapted-personalized search: based on the previous two stages, the system uses the recommendation principles mechanism to offer for the user results wthat origin with the most appropriate search engine for the *query type* and in accordance with the *question type*.

5 METHODOLOGY

The iterative development of CASA follows the five stages of system development: planning, analysis, design, implementation and evaluation. This process is discussed herein.

Planning & Analysis: involved the consideration of 1) the search engines to be included in this research, and of 2) the search terms to be used for query formulation. Several trial quarries were run using different search engines for the purpose of identifying appropriate (i.e., unique and distinguished) search engines and terms in a manner that will assure heterogeneity of technology and ontological diversion of query elements.

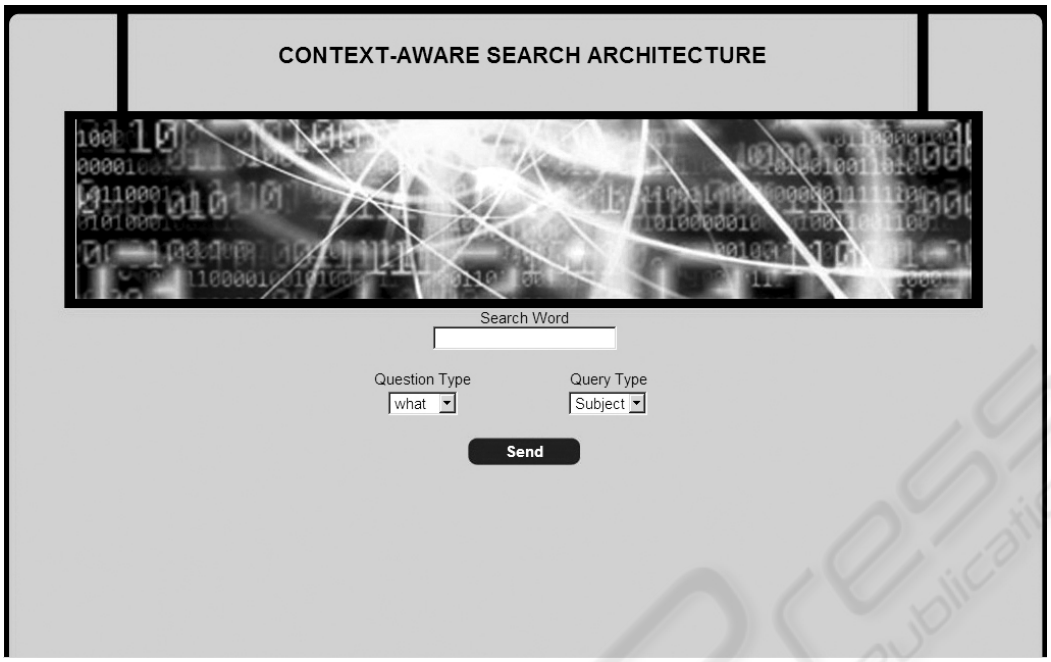


Figure 1: Context-aware search interface.

For the latter we have found theoretical grounds in the Ontology for Social Knowledge Application (OSKA; Weinberger, 2010). Eight search engines were selected based on the distinct definition of each and following hands-on, ongoing experience. The selection process was motivated towards emphasising the novelty of the search engine technology, to include: Google as a popularity-based SE, Hakia as a Semantic- and Social-Semantic SE, Kartoo and Clusty as visualized and clustering SEs and FreeBase as analytic and social-semantic SE. Last but not least are Feedmil and WolframAlpha. The former is a social-, hybrid and long tail search engine and the latter is an analytic- and semantic search engine (see section 2).

Design: was focused upon 1) query formulation – in accordance with the ontological perspectives of OSKA. Query elements were defined to meet the three perspectives view of the aforementioned ontology. For each search engine three queries were introduced, using: a) an element of the content perspective (e.g., Web 2.0 tools, Web 2.0 software, social media applications, b) an element of the task perspective (e.g., collaboration, participation, publishing, editing, reporting) and c) an element of the technology perspective (e.g., bookmarks, blog, Wiki, Microbloging, Database).

Yet as part of design we managed 2) the modification and extension of the list of search engines, alongside 3) analysis of search results by the six WH questions. An analysis and documentation scheme was designed specifically for this end (Figure 2). This scheme is also used for in-class assignments as part of students education towards the implementation of the method suggested here.

Implementation: involved 1) the definition of the recommender principles. This was done based on the analysis of previous results. The analysis and design process followed the WH questions in order to identify the relationship between a search engine and an ontological perspective, using the aforementioned analysis and documentation scheme. The findings of the former activities (i.e., the recommendation principles and the query modification techniques) were used for 2) the design of the prototype Web interface. Last but not least we mention integration into curriculum of the advised method reported in this paper.

Evaluation: evaluation in this research followed two lanes. The first is evaluation through design and the second is empirical evaluation aiming at the feasibility and usefulness of the architecture – the RPs and query modification techniques. We elaborate on the latter evaluation course.

First, the method, as embedded in the design of the Web interface (prior to design) was introduced as part of the 'Web technologies' course syllabus in two distinct university classes. The first is graduate students of a business class in the University of Nicosia, Cyprus and the second id undergraduate

students of our institution. All the students followed this method for the allocation of resources for their term projects. These projects were aiming at: developing subject-specific knowledge sharing systems (e.g., Bibsonomy, Twine, Google Bookmarks), the design of Mashup application (e.g., iGoogle, netvibes) and of Web-based Learning Objects – using a spectrum of Web 2.0 tools.

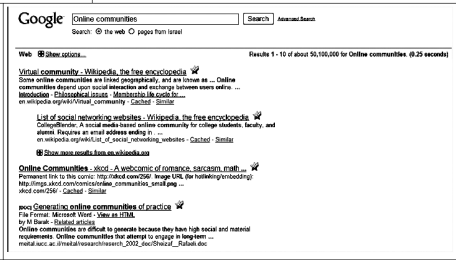
Query : Online communities	**Search Engine name**: Google	**Search Engine Type:** Popularity-based
Aspect: Scope	**Recommendation Principle**	
Screen Print:		
Outcome Feedback	Results are aiming at: the description of the phenomenon, reference to example sites, guides etc.	
WH	**(e.g.,) *What,* When, Who, *Where,* Why, How**	

Figure 2: An example analysis and documentation scheme.

6 CONCLUSIONS

This paper suggests a context-aware search architecture which supports several processes and activities such as the: a) identification and the modification of user requirements and the b) manipulating between search engines, hence, facilitating the use of a c) recommender system based on recommendation principles embedded in this architecture and demonstrated by the prototype Web interface.

The suggested framework – including the method, the recommendation principles and the system architecture, was developed in accordance with the hypothesis suggested earlier in this paper regarding usability obstacles in practicing conventions. The context-aware search architecture advised in this research utilizes a spectrum of search technologies, determined based on the relative value predicted for the user's model, while aiming towards enhanced precision.

There are three deliverables to this research in accordance with the three goals set for this research. The first is the method, prescribing guidelines for context-aware query modification. Second are the recommendation principles directing the utilization of search engines in context and serving as basis for the design of the architecture as demonstrated through the prototype Web interface, which is the third deliverable that builds on the former two deliverables to suggest a user- adapted HCI experience. This interface allows users – regardless of their domain of practice, in enterprise setting as part of business interactions, or else as part of academic setting; an innovative, dynamic and context-aware search interaction.

The findings of this research indicate a relationship between a) the *search engine* type and the *ontological perspectives* of the query on the one hand, and between b) the results obtained by the search operation, on the other hand. For this reason, a search engine can be recommended, and the query may be modified, based on the identification of the query's aspect.

There are several limitations to the research reported here. Indeed, based on our experience the feasibility and the usefulness of our method were demonstrated in the field. However, further empirical evaluation can be carried out to extend beyond the scope of the examples used here, as well as with regard to search engines and quantitative results.

We believe that the findings from our study have implications beyond this immediate setting. Several further research directions may be instructed based on this research. First, we mention the automation of the interface features, which could be supported provided adequate ontologies, for instance as part of Web 3.0, are incorporated as part of this architecture. Second is the extension of the Web-interface beyond the prototype features introduced here. Last but not least is the inclusion of Semantic Web (i.e., Web 3.0) technologies, such as artificial intelligence and natural language processing, for the next-generation of the suggested framework.

All in all, CASA, as suggested here, can improve and expand the current Web search experience of individual users, organizations or designers. This work should prove useful to anyone considering the development of Web search architecture, or else individuals seeking to enhance their exploratory search experience.

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