Logic-Based Adaptive Information Agents on the Web

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ABSTRACT
Adaptive information agents have been developed to alleviate the problem of information overload on the Internet. However, the *learning autonomy* and the *explanatory power* of these agents are weak. Logic-based approaches for representation, learning, and matching in adaptive information agents are promising since users' changing information needs can be automatically deduced by the agents. In addition, learning and retrieval behaviour of the agents can be explained and justified based on formal deduction.

Keywords
Belief Revision, Adaptive Information Agents.

1. INTRODUCTION
Prototypes of adaptive information agents have been developed to alleviate the problem of information overload on the Web [2, 5]. However, the *learning autonomy* and the *explanatory power* of these agents are weak. One distinct feature of adaptive information agents is their capability of revising the representations of the users' information needs with respect to the users' current preferences. The *AGM* belief revision paradigm [1] provides a rich and rigorous foundation for modelling the revision processes. It enables an agent to modify its beliefs in a *minimal* and *consistent* way. This corresponds to the intuition of updating a user profile in information retrieval. Since semantic relationships (e.g. synonyms, polysemes, specialisation) [3] among information items are reasoned about during the belief revision process, information agents can automatically deduce users' changing information needs given minimum amount of direct relevance feedback [6]. Consequently, a higher level of *learning autonomy* is achieved. As the agents' learning processes are formalised by the belief revision logic, their learning behaviour can be explained based on logical deduction.

2. SYSTEM ARCHITECTURE
Figure 1 depicts the agent-based information retrieval and filtering system on the Web. The focus of this paper is the *adaptive information filtering agent*. The *matching module* of the filtering agent compares the logical representation of each incoming information object stored in a local database with the user profile (i.e. the representation of a user's topical information needs). If there is a sufficiently close match between these representations, the information object will be transferred to another local database of filtered information objects. This matching process is underpinned by nonmonotonic inference [4]. A user possesses a set of filtering agents, with each one of them representing the information needs of a particular topic (e.g. the Yahoo topic "Finance and Investment"). Accordingly, an incoming information object is examined by each filtering agent in order to determine its relevance with respect to the user's information needs. The *interface agent* dispatches the filtered information objects from a local database to the user. After viewing the presented objects, the user provides relevance feedback about these objects to the system. Essentially, it is a binary judgment of whether an information object is relevant or not. The relevance feedback information is then stored along with the corresponding information objects in the local database. Moreover, implicit feedback such as a bookmark or the duration of viewing a particular object can be also used to infer the relevance of a viewed object. At each learning cycle (e.g. after every n objects are viewed), the *learning modules* of the filtering agent analyses the relevance feedback information pertaining to viewed objects which have been filtered by them before. The resulting statistical data is used to induce the beliefs [1] about a user's information needs. These beliefs are then revised into the pertaining user profiles by means of the maxi-adjustment belief revision method [7]. In particular, a profile is modified in a *minimal* and *consistent* way with maximal information inertia. Revised profiles are then used by the filtering agents for subsequent information matching. The retrieval agents (RA) act as *wrappers* to external information sources. They inquire about a user's information preferences through the filtering agents and translate these preferences to appropriate queries. The queries are then passed to the Internet search engines or external agents for information retrieval. After collecting the preliminary query results from external information sources, the retrieval agents will put the information objects in a local database for subsequent matching.

3. LEARNING AND ADAPTATION
Table 1 shows an example of applying the maxi-adjustment method [7] to revise a filtering agent's knowledge base (i.e. the user profile). The first column depicts the set of beliefs (i.e. first order formulae) representing a user's information needs. The ground term of the *positive identifier* predicate *pid* describes an information object required by the user. The second column lists the entrenchment degree of corresponding beliefs before a learning cycle takes place. The third column depicts the results after belief revision. A zero entrenchment degree means that the corresponding belief is not contained in the agent's knowledge base. Assuming that the user is interested in information objects (e.g. Web pages) about "Sculpture" with entrenchment (certainty) 0.785, the belief revision process $\mathbf{B}^{\star}(pid(sculpture), 0.785)$ is invoked. After belief revision, the agent can automatically deduce that the user may be

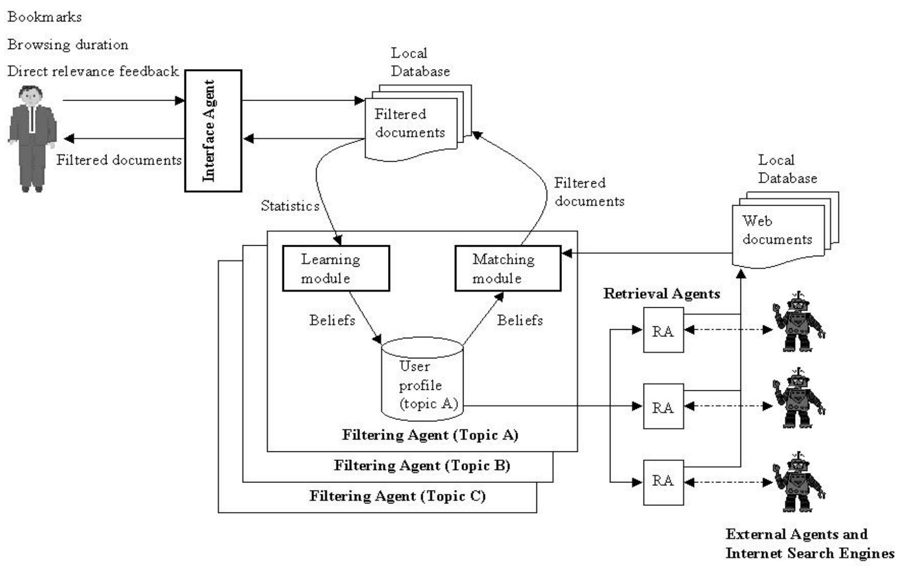

Figure 1: Adaptive Information Agents on the Web

interested in information objects about "Art" but may not be interested in information objects about "Business". The explanation of such a prediction can be based on formal deduction (e.g. modus ponens).

Belief:α	$\mathbf{B}(\alpha)$ Before	$\mathbf{B}(\alpha)$ After
$pid(sculpture) \rightarrow pid(art)$	1.000	1.000
$pid(business) \rightarrow \neg pid(art)$	0.600	0.600
$pid(sculpture)$	0	**0.785**
$pid(art)$	0	**0.785**
$\neg pid(business)$	0	**0.600**

Table 1: Maxi-adjustment of Beliefs

4. MATCHING WEB DOCUMENTS

Matching in a filtering agent is underpinned by nonmonotonic inference [4]. A Web document is taken as the conjunction of a set of formulae. If the filtering agent's knowledge base K nonmonotonically entail $\mid\!\sim$ the logical representation of a Web page ϕ, the corresponding document D_ϕ will be considered as relevant. For example, if the knowledge base K is used to determine the relevance of the two Web pages D_ϕ and D_φ, the results are as follows:

$$K = Cn(\{(pid(business) \rightarrow \neg pid(art), 0.600), (pid(sculpture) \rightarrow pid(art), 1.000), (pid(sculpture), 0.785)\})$$

$$\varphi = \{pid(business) \wedge pid(art)\}$$
$$\phi = \{pid(sculpture) \wedge pid(art)\}$$

$$\therefore \quad K \not\mid\!\sim \varphi, \quad K \mid\!\sim \phi$$

5. DISCUSSION AND FUTURE WORK

The AGM belief revision logic opens the door to more responsive learning processes in adaptive information agents. Moreover, it also facilitates the explanation of the agents' learning and retrieval behavior. A prototype system is under development based on the object-oriented belief revision engine developed in Java 2 [8]. Future work involves formal evaluations of the effectiveness and the efficiency of the adaptive information agents. In particular, the benchmarking process used at the TREC conference for evaluating adaptive information filtering systems will be adopted to assess the effectiveness of our proposed system.

6. REFERENCES

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