Intelligent Text Handling Using Default Logic

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Abstract

There is a need to develop more intelligent means for handling text in applications such as information retrieval, information filtering, and message classification. This raises the need for mechanisms for ascertaining what an item of text is about. Even though natural language processing offers the best results, it is not always viable. A less accurate, but more viable alternative, is to reason with keywords in the text. Unfortunately, classical reasoning is often inadequate for determining from some keywords what a text is about. In particular, it does not allow context-dependent interpretation of keywords. So for example, if some text has the keyword oil*, it is usually also about* $minerals$*, though with exceptions such as when it has the keyword* $cooking$*. To address this kind of problem, we consider a model of "aboutness" based on default logic.*

1 Introduction

There is a need to develop more sophisticated, more intelligent, means for handling textual information in computing. Take for example applications such as the following:

- Filtering useful reports from newsfeeds.
- Classifying emails according to type, ugency, or importance.
- Retrieving information from large databases.
- Routing documents in a groupware system.
- Indexing online documentation.

For each of these applications, it is desirable to have some understanding of what the text is about. Whilst, full natural language understanding techniques offer the ultimate solution, they currently do not offer generally viable solutions. A compromise is to use keywords in textual information to obtain some approximation of what the information is about. This then raises the need to better understand the notion of "aboutness". For example, if we know that a newspaper article is about oil is it reasonable to always derive that it is about $petroleum$. If it is not always reasonable to make such a derivation, can we identify exceptions, such as the article is about $cooking\text{-}oil$?

The notion of "aboutness" has been investigated in fields such as information retrieval, but this has not generated an adequate formalization [5]. Recently, the non-monotonic nature of aboutness has been identified [4, 10]. This paper provides a theoretical framework for aboutness based on default logic, which could be developed for applications.

2 Classical logic for handling aboutness

In this section, we show how classical logic can form the basis of a framework for handling information about textual information.

2.1 Keyphrases

Definition 2.1 *Let* $\mathcal{K}$ *be a set of propositional letters, which we call the set of keywords. Let* $\mathcal{L}$ *be the usual set of formulae formed from* $\mathcal{K}$ *and the connectives* $\{\neg, \vee, \wedge\}$*. We call* $\mathcal{L}$ *the set of keyphrases.*

Definition 2.2 *We assume that any item of textual information has an associated keyphrase, called an item keyphrase.*

For example, in a database on articles from a magazine, the keyphrase for each item could be generated by first deleting less informative words, called stop words, such as the, a, and $because$, and then using the conjunction of the remaining words in the article as the keyphrase. Though in practice it is likely we would use more sophisticated algorithms for identifying important keywords, based on statistical techniques that have been developed for information retrieval and information filtering [19, 17].

Definition 2.3 *The second kind of keyphrase is the request keyphrase. This can be any formula from $\mathcal{L}$, and it represents the user's delineation of information that is relevant for a task or a classification.*

For example, in a information retrieval system for a bibliograhic database, a request keyphrase represents a delineation of the bibliographic entries that are of interest to the user. So, if the user has the request keyphrase, $france \vee spain$, the user is seeking items on $france$ or $spain$. Similarly, if the user has the request keyphrase $usa \wedge trade$, then the user is seeking items that are on both usa and $trade$. As another example, if the user has the request keyphrase $\neg politics$, the user is seeking items that are not on $politics$.

2.2 Satisfying requests with items

Definition 2.4 *Let α be an item keyphrase and β be a request keyphrase. The item satisfies the request iff $\{\alpha\} \vdash \beta$ holds, where $\vdash$ is the classical consequence relation.*

For example, suppose in a database of articles from a magazine, there is an item with the keyphrase $france \wedge skiing$, and there is a request keyphrase $skiing$. In this case, the item satisfies the request, since $france \wedge skiing \vdash skiing$ holds.

2.3 Aboutness requires more than classical logic

Determining what an item, or request, is about depends heavily on the choice of keyphrase. For example, consider the keywords car, $automobile$ and *motor-car*. These keywords are all usually about each other, yet they do not classically imply each other. However, adding a classical formula stating that they are equivalent is not satisfactory since there are exceptions to this general rule, such as when car is about *railway-car*. In this way, classical logic is inadequate for handling the required general rules with exceptions. As a result there is a need for context-dependent rules for augmenting what a keyphrase is about.

As second kind of example, consider the keyphrase *computer-network* $\vee$ *academic-communications*. In some contexts, such as a university computing department library, this might be regarded as a very general keyphrase, and hence not very helpful. Furthermore, it is quite likely that, in that context, this keyphrase is really about the more specialized topic of $internet$. In this case, the keyphrase is about a keyword that does not follow classically from the keyphrase, and furthermore, it might be desirable for the keyphrase to not be described as being about itself. Again, classical logic is inadequate for the task. As a result, there is a need for context-dependent rules for restricting what a keyphrase is about.

Since keyphrases are formulae, context-dependent rules for augmenting or restricting what a keyphrase is about need to be presented as a meta-langauge for $\mathcal{L}$. Adopting such an approach also raises the need for axioms to manipulate these meta-level statements. In addition, there will be a need for a new definition of an item satisfying a request based on the item keyphrase being about the request keyphrase.

To summarize, in a new framework for handling aboutness, we have the following requirements: [R1] Context-dependent meta-level rules for restricting what a keyphrase is about; [R2] Context-dependent meta-level rules for augmenting what a keyphrase is about; [R3] Axioms for manipulating statements on what a keyphrase is about; and [R4] A new definition for satisfying requests with items. We address these requirements in the next section.

3 Default logic for handling aboutness

In this section, we extend the framework presented in the last section. For this we assume default logic [16], and use it for meta-level reasoning about keyphrases. In particular, we assume the usual definition of a credulous extension for a default theory.

In the following we use a relation $about(\alpha, \beta)$ to denote that the keyphrase α is "about" the keyphrase β. For example, the relation $about(car, automobile)$ is capturing the fact that car is about $automobile$. Similarly, the relation $about(railway \wedge network, transport)$ is capturing the fact that $railway \wedge network$ is about $transport$. As another example, $about(sciences, \neg arts)$ is capturing the fact that $sciences$ is about things excluding $arts$. Note, we will see that this is different to $\neg about(sciences, arts)$ which just captures the fact that it is not the case that $sciences$ are about $arts$. In the following, we present a language and a proof theory for reasoning with the $about$ relation.

3.1 Language for aboutness

Definition 3.1 *Let $\mathcal{C}$ be a set of constant symbols, such that if $\alpha \in \mathcal{K}$, then $\alpha \in \mathcal{C}$. Let $\mathcal{F}$ be a set of function symbols, such that each classical connective in $\mathcal{K}$ is a function symbol in $\mathcal{F}$. Let $\mathcal{V}$ be a set of variable symbols. Let $\mathcal{T}$ be the usual set of terms formed from $\mathcal{C}, \mathcal{F}$, and $\mathcal{V}$, such that if $\alpha \in \mathcal{L}$, then $\alpha \in \mathcal{T}$. Let $\mathcal{P}$ be a set of predicate symbols that includes $item$, $proves$, $about$, and $exception$.*

Definition 3.2 *Let $\mathcal{M}$ be the usual language of first-order classical logic formed from the usual classical connectives, where $item$ and $exception$ are monadic relations ranging over $\mathcal{L}$, and $proves$ and $about$ are binary relations ranging over $\mathcal{L}$.*

In this way $\mathcal{M}$ is a meta-language for $\mathcal{L}$. We now use $\mathcal{M}$

as the classical language for defining default rules, as follows.

Definition 3.3 *Let $\mathcal{D}$ be the set of default rules of the following form.*

$$\frac{\alpha \ : \ \beta}{\gamma}$$

where $\alpha, \beta, \gamma \in \mathcal{M}$.

Definition 3.4 *In the following we use the relation $item(\alpha)$ to denote that the item keyphrase is α, and we use the relation $about(\alpha, \beta)$ to denote that the keyphrase α is "about" the keyphrase β.*

Definition 3.5 *The relation $proves(\alpha, \beta)$ holds iff $\alpha \vdash \beta$ holds, where $\vdash$ is the classical consequence relation.*

In section 5, we will consider further relations in $\mathcal{M}$.

3.2 Generating $about$ relations from the item keyphrase

In this section, we address the [R1] requirement. For any item keyphrase α, and any β, such that $\alpha \vdash \beta$, it is not necessarily the case that $about(\alpha, \beta)$ holds. In this way we can restrict what we infer α is about. Therefore, given $item(\alpha)$, and $\alpha \vdash \beta$, we do need to determine when we can derive $about(\alpha, \beta)$. In other words, we need to have conditions for generating $about$ relations from the item keyphrase. For this we use the rule for default inclusion, defined below, or the positioning rules, defined in section 3.3, or the axioms for the $about$ relation defined in section 3.4.

Definition 3.6 *The rule for default inclusion allows the relation $about(\alpha, \beta)$ to be derived if β is a classical consequence of the item keyphrase and β is not an exception.*

$$\frac{proves(\alpha, \beta) \wedge item(\alpha) : \neg exception(\beta)}{about(\alpha, \beta)}$$

Above, we see that the default rule for inclusion can be blocked. For example, if we assume $exception(car)$, then we cannot derive $about(\alpha, car)$. In section 3.5, we continue this example and see how we can use positioning rules to allow us to derive $about(\alpha, car)$ for some α.

3.3 Positioning rules for the $about$ relation

In this section, we address the [R2] requirement. For this we provide context-dependent rules, called positioning rules, for augmenting what a keyphrase is about. Positioning rules are any default rules that allow for the derivation of further $about$ relations.

Definition 3.7 *Positioning rules are default rules of the following form:*

$$\frac{Condition \ : \ Justification}{about(\alpha, \beta)}$$

where Condition, Justification $\in \mathcal{M}$.

For example, the consider the following default rule.

$$\frac{\begin{array}{l} about(\alpha, trade \wedge usa \\ \qquad\qquad \wedge (mexico \vee canada)) : about(\alpha, nafta) \end{array}}{about(\alpha, nafta)}$$

This default can be interpreted as follows: If we can derive the following,

$$about(\alpha, trade \wedge usa \wedge (mexico \vee canada))$$

and it is consistent to derive $about(\alpha, nafta)$, then we derive $about(\alpha, nafta)$. As another example, consider the following positioning rule.

$$\frac{proves(\alpha, car) \wedge about(\alpha, railway) : about(\alpha, wagon)}{about(\alpha, wagon)}$$

Here, if α classically implies the keyword car, and $about(\alpha, railway)$ holds, then $about(\alpha, wagon)$ holds.

3.4 Axioms for the $about$ relation

In this section, we address the [R3] requirement. For this we provide a means for logically manipulating the $about$ relation: The following definition provides classical reasoning with the formulae on the right-hand side of the $about$ relation.

Definition 3.8 *If $\beta_1, ..., \beta_n \vdash \gamma$, then the following is an axiom for the about relation,*

$$about(\alpha, \beta_1) \wedge ... \wedge about(\alpha, \beta_n) \rightarrow about(\alpha, \gamma)$$

Useful axioms that follow from this definition include the following,

$$about(\alpha, \beta \wedge \gamma) \rightarrow about(\alpha, \beta)$$

$$about(\alpha, \beta) \wedge about(\alpha, \gamma) \rightarrow about(\alpha, \beta \wedge \gamma)$$

$$about(\alpha, \beta) \rightarrow about(\alpha, \beta \vee \gamma)$$

$$\neg about(\alpha, \beta) \rightarrow \neg about(\alpha, \beta \wedge \gamma)$$

Axioms that follow from definition 3.8 are used for reasoning with $about$ statements. For example, suppose we have $about(car, car)$ and $about(car, automobile)$, then we have $about(car, car \wedge automobile)$.

3.5 Reasoning with the $about$ relation

In this section, we address the [R4] requirement by showing how given an item keyphrase, and a request keyphrase, we can determine whether the item satisfies the request.

Definition 3.9 *Let Δ denote the set of rules for default inclusion, the exceptions to default inclusion, the axioms for the $about$ relation, and the positioning rules. We call Δ the positioning set.*

Definition 3.10 *Let α be an item keyphrase, β be a request keyphrase, and Δ be a positioning set. Let (D,W) be a default theory formed from a partition of $\Delta \cup \{item(\alpha)\}$ into elements from $\mathcal{D}$ and $\mathcal{M}$ respectively. The relation $about(\alpha, \beta)$ follows from Δ iff there is an extension E of (D,W), according to Reiter's definition of default logic [16], such that $about(\alpha, \beta) \in E$.*

By definition 3.10, the default theory (D, W) is such that D contains the default inclusion rules and positioning rules, and W contains the exception formulae, the item formula, and the axioms for the about relation. We now provide a new definition for an item satisfying a request.

Definition 3.11 *Let α be an item keyphrase, β be a request keyphrase, and Δ be a positioning set. The item satisfies the request iff the relation $about(\alpha, \beta)$ follows from Δ.*

Example 3.1 Consider the request keyphrase $nafta \vee eu$, and the following positioning rule.

$$\frac{about(\alpha, trade \wedge usa \wedge (mexico \vee canada)) : about(\alpha, nafta)}{about(\alpha, nafta)}$$

Also suppose there is only one item, and it has the item keyphrase $trade \wedge usa \wedge mexico$. Hence, we obtain the following,

$$item(trade \wedge usa \wedge mexico)$$

For the item to satisfy the request, we require the following to hold,

$$about(trade \wedge usa \wedge mexico, nafta \vee eu)$$

This can be satisfied if we can show one of the following to hold.

$$about(trade \wedge usa \wedge mexico, nafta)$$
$$about(trade \wedge usa \wedge mexico, eu)$$

By default inclusion, we obtain the following from the item keyphrase,

$$about(trade \wedge usa \wedge mexico, trade)$$
$$about(trade \wedge usa \wedge mexico, usa)$$
$$about(trade \wedge usa \wedge mexico, mexico)$$

And by the axioms for aboutness, we obtain the following,

$$about(trade \wedge usa \wedge mexico, trade \wedge usa \wedge (mexico \vee canada))$$

Now by application of the only positioning rule, we can obtain the following,

$$about(trade \wedge usa \wedge mexico, nafta)$$

Hence, we can satisfy the request with the item.

In the above example we can see that reasoning with the $about$ relation brings the meaning of the item and the request keyphrases together. It acts as a bridge.

Example 3.2 As we indicated in the section on generating $about$ relations, we can use positioning rules in addition to the rule for default inclusion. For example, consider the following positioning rule.

$$\frac{proves(\alpha, car) : \neg about(\alpha, railway)}{about(\alpha, car)}$$

For $item(car)$, $about(car, railway)$ does not follow. So, we can obtain $about(car, car)$, since the justification $\neg about(car, railway)$ is consistent with the extension.

Example 3.3 Now, suppose we have $item(railway \wedge car)$, and a request keyphrase, $railway \wedge wagon$. Also suppose that we have the following exception for the rule of default inclusion, the following positioning rules.

$$exception(car)$$

$$\frac{proves(\alpha, car) : \neg about(\alpha, railway)}{about(\alpha, car)}$$

$$\frac{proves(\alpha, car) \wedge about(\alpha, railway) : about(\alpha, wagon)}{about(\alpha, wagon)}$$

From the request, we need to show the following,

$$about(railway \wedge car, railway \wedge wagon)$$

For this we need to satisfy both the following, according to the axioms for $about$.

$$about(railway \wedge car, railway)$$
$$about(railway \wedge car, wagon)$$

From the item and the default inclusion, we can show the first relation, and from the positioning rule, we can show the second rule. Note, the relation $about(railway \wedge car, car)$ cannot be obtained.

4 Properties of the $about$ relation

In this section, we consider a characterization of the $about$ relation as a form of non-standard consequence relation.

Proposition 4.1 *The $about$ relation is not reflexive, transitive, symmetric, asymmetric, antisymmetric, monotonic, or supraclassical, where these properties are defined, respectively, as follows, and $\alpha, \beta, \gamma \in \mathcal{L}$.*

$$about(\alpha, \alpha)$$

$$(about(\alpha, \beta) \wedge about(\beta, \gamma)) \rightarrow about(\alpha, \gamma)$$

$$about(\alpha, \beta) \rightarrow about(\beta, \alpha)$$

$$about(\alpha, \beta) \rightarrow \neg about(\beta, \alpha)$$

$$(about(\alpha, \beta) \wedge about(\beta, \alpha)) \rightarrow (proves(\alpha, \beta) \wedge proves(\beta, \alpha))$$

$$about(\alpha, \beta) \rightarrow about(\alpha \wedge \gamma, \beta)$$

$$proves(\alpha, \beta) \rightarrow about(\alpha, \beta)$$

For each of these properties, we can identify a positioning set such that the property does not hold.

Referring back to the discssion in Section 2.3, we expect reflexivity to fail, because we believe that it is natural that a keyphrase can be about a more specialized, or partially different, topic than is classically implied (as in Example 3.3). Following this argument, we do not expect any of the other properties in Proposition 4.1 to hold.

Proposition 4.2 *Left logical equivalence, right weakening, and consistency preservation, defined below, respectively, do hold for any positioning set, where $\alpha, \beta, \gamma \in \mathcal{L}$.*

$$(about(\alpha \wedge \gamma, \beta) \wedge proves(\gamma, \delta) \wedge proves(\delta, \gamma)) \rightarrow about(\alpha \wedge \delta, \beta)$$

$$(about(\alpha, \beta) \wedge proves(\beta, \gamma)) \rightarrow about(\alpha, \gamma)$$

$$about(\alpha, \bot) \rightarrow proves(\alpha, \bot)$$

An undesirable consequence of any positioning set is $about(\alpha, \bot)$, since this means that α is about everything. We therefore need to show for any positioning set that the following holds for all α, $\neg about(\alpha, \bot)$. If we can show this, we then obtain the following axioms for reasoning with the about relation.

Proposition 4.3 *For any $\alpha, \beta \in \mathcal{L}$, if $\neg about(\alpha, \bot)$ holds, then the following axiom holds.*

$$\neg about(\alpha, \beta) \vee \neg about(\alpha, \neg\beta)$$

Though the following axiom does not hold in general.

$$about(\alpha, \beta) \vee about(\alpha, \neg\beta)$$

Proposition 4.4 *Let α be an item keyphrase, β be a request keyphrase, and Δ be a positioning set. For this $proves(\alpha, \beta)$ does not necessarily imply that $about(\alpha, \beta)$ follows from Δ. Similarly, if $about(\alpha, \beta)$ follows from Δ, this does not necessarily imply $proves(\alpha, \beta)$ holds.*

Proposition 4.5 *Let α be an item keyphrase, β be a request keyphrase, and Δ be a positioning set, where there are no exceptions and no positioning rules in Δ. In this case, the about relation is reflexive, transitive, antisymmetric, monotonic, and supraclassical (where these properties are defined in proposition 4.1).*

In another logical approach to analysing the notion of aboutness, a monotonic consequence relation, extended with a form of closed world assumption, has been used as an aboutness relation [4]. However, the approach lacks the facility for default reasoning, which as we discussed in section 2.3, is problematical.

Conditional logics [20, 6] and terminological logics [13] have been proposed to relate information in items with information requests using logical implication. However, these approaches also lack adequate default reasoning capability.

Elsewhere, aboutness has been analysed in the form "sentence p is about topic t" [8]. The formalization differs significantly from the approach in this paper. For example, given that a sentence q is about t, their approach accepts that $\neg p$ is also about t.

5 Developing the framework

There are a number of ways this framework can be developed. We briefly consider preclusion rules and using further meta-level relations here.

5.1 Preclusion rules for the $about$ relation

Preclusion rules are a complementary form of default rule to the positioning rules. These context-dependent rules preclude some $about$ relations in some contexts, and are therefore useful for handling polysemes.

Definition 5.1 *Preclusion rules are default rules of the following form:*

$$\frac{Condition\ :\ Justification}{\neg about(\alpha, \beta)}$$

where Condition, Justification $\in \mathcal{M}$.

For example, consider the following preclusion rule.

$$\frac{about(\alpha, car \wedge lisp)\ :\ \neg about(\alpha, automobile)}{\neg about(\alpha, automobile)}$$

Here, if we have the relation $about(\alpha, car \wedge lisp)$, and it is consistent to derive $\neg about(\alpha, automobile)$, then we can preclude the possibility that α is about for example $automobile$. In this way, each preclusion rule forces a different extension for each different meaning of a keyphrase.

5.2 Using further meta-level relations

To describe an item being about some topic depends very much on the type of item, and also on the type of request. Therefore, we really need to enhance the preconditions and justifications for our default rules to take this into account.

As a simple example, in order to describe a newspaper article as being about a particular topic, the keywords in the first few sentences are far more important than keywords in later sentences.

As another example, peoples names are particularly important keywords for identifying what an article on politics is about. Similarly, company names are particularly important for identifying what financial articles are about.

Clearly, formulae in $\mathcal{M}$ can be used to capture the reasoning behind such examples, and provide better positioning and preclusion rules.

6 Discussion

Reasoning with keywords, and in particular ascertaining what keywords are about, are important issues in computing [11]. Clearly, the choice of keyphrase can significantly affect the quality of the text handling. For example, in information retrieval, the choice can affect the recall (the proportion of appropriate items that are retrieved) and the precision (the proposition of retrieved items that are appropriate). A keyphrase might be based on concepts too general, or too specialized, or may fail to incorporate important synonyms. For each keyphrase, it is important to consider whether a more general, or specialized keyphrase should be used, or whether it should be used with some synonym, or even replaced by another keyphrase. This kind of reasoning can be supported by using the framework for aboutness discussed in this paper.

Basing the framework on default logic brings advantages. Default logic provides an efficient representation for context-dependent reasoning and handling of exceptions, and it is a well-understood formalism for representing uncertain information. A number of variants of default logic have been proposed that provide a range of capabilities (for example [2, 3]) and relationships with probability theory are being established (for example [1, 7]). Preferences over default rules, such as for more specific defaults, can be handled directly using the justification condition on a rule, or by explicitly representing priorities over defaults (see for example [3]).

Supporting technology for default logic is now being developed. There are prototype implementations of inference engines for default logic that can be used for developing default logic knowledge-bases [15, 12, 18]. Furthermore, there are methods for compiling default logic knowledge-bases for viable implementations of developed knowledge-bases.

For an application, it is possible that a relatively large number of default rules would be required for an acceptable level of performance. To address this viability problem, we are investigating a number of avenues: (1) Using the framework in restricted domains that require a limited number of default rules; (2) Using inductive logic programming ([14]) to generate default rules for a domain; (3) Using statistical techniques to identify important keywords for a given domain; and (4) Using machine-readable lexicons such as WordNet [9].

Acknowledgements

This work has been supported by the ESPRIT DRUMS2 project and the EPSRC VOILA project. The author is grateful to Peter Bruza, Beatrice Duval, Mounia Llamas, Pascal Nicolas, Keith van Rijsbergen, Fabrizio Sebastiani, and Torsten Schaub for much feedback on this work.

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