Intelligent Web Querying with Logic Programs

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Abstract

We present a general framework for the information extraction from web pages based on a special wrapper language, called *token-templates*. By using *token-templates* in conjunction with logic programs we are able to reason about web page contents, search and collect facts and derive new facts from various web pages. We give a formal definition for the semantics of logic programs extended by *token-templates* and define a general answer-complete calculus for these extended programs. These methods and techniques are used to build intelligent mediators and web information systems.

Keywords: information extraction; template based wrappers; mediators; logic programming; theory reasoning; deductive web databases; softbots; logic robots.

1 Introduction

In the last few years it became appearant that there is an increasing need for more intelligent World-Wide-Web information systems. The existing information systems are mainly document search engines, e.g. *Alta Vista, Yahoo, Webcrawler*, based on indexing techniques and therefore only provide the web user a list of document references and not a set of facts he is really searching for. These systems overwhelm the user with hundreds of web page candidates. The exhausting and highly inconvenient work to check these candidates and to extract relevant information manually is left to the user. The problem gets even worse if the user has to take comparisons between the contents of web pages or if he wants to follow some web links on one of the candidate web pages that seem to be very promising. Then he has to manage the candidate pages and has to keep track of the promising links he has observed.

To build intelligent web information systems we assume the WWW and its web pages to be a large relational database, whose data and relations can be made available by the definition and application of special extraction descriptions (*token-templates*) to its web pages. A library of such descriptions may then offer various generic ways to retrieve facts from one or more web pages. One basic problem we are confronted with is to provide means to access and extract the information offered on arbitrary web pages, this task is well known as the process of *information extraction* (IE). The general task of IE is to locate specific pieces of text in a natural language document, in this context web pages. In the last few years many techniques have been developed to solve this problem (1; 4; 9; 10; 15; 21; 29), where *wrappers* and *mediators* fulfil the general process to retrieve and integrate information from heterogeneous data sources into one information system.

We focus our work on a special class of wrappers, which extract information from web pages and map it into a relational representation. This is of fundamental interest because it offers a wide variety of possible integrations into various fields, like relational databases, spreadsheet applications or logic programs. We call this information extraction process *fact-retrieval*, due to logic programming the extracted information is represented by ground atoms. In this paper we present a general framework for the fact retrieval based on our special wrapper language, called *token-templates*. Our general aim was to develop a description language for the IE from semi-structured documents, like web pages are. This language incorporates the concepts of *feature structures* (24), *regular expressions*, *unification*, *recursion* and *code calls*, to define templates for the extraction of facts from web pages.

How does this contributes to *logic programming*? The key idea of using logic programs for intelligent web browsing is as follows: Normally the user is guided by his own domain specific knowledge when searching the web, manually extracting information and comparing the found facts. It is very obvious that these user processes involve inference mechanisms like reasoning about the contents of web pages, deducing relations between web pages and using domain specific background knowledge.Therefore he uses deduction, based on a set of rules, e.g. which pages to visit and how to extract facts. We use logic programs in conjunction with token-templates to reason about the contents of web pages, to search and collect relevant facts and to derive new facts from various web pages. The logic programming paradigm allows us to model a background knowledge to guide the web search and the application of the extraction templates. Furthermore the extracted facts in union with additional program clauses corespond to the concept of deductive databases and therefore provide the possibility to derive new facts from several web pages. In the context of *wrappers* and *mediators* (29), *token-templates* are used to construct special wrappers to retrieve facts from web pages. Logic programs offer a powerful basis to construct mediators, they normalize the retrieved information, reason about it and depending on the search task to fulfil, deduce facts or initialize new sub searching processes. By merging token-templates and logic programs we gain a mighty inference mechanism that allows us to search the web with deductive methods. We emphasize the well defined theoretical background for this integration, which is given by *theory reasoning* (2) (25) in logical calculi, whereas *token-templates* are interpreted as theories.

The paper is organized as follows: in Section 2 we describe the language of *token-templates* for the fact-retrieval from web pages. In Section 3 we explain the integration of *token-templates* into logic programs and the underlying $\mathcal{T}_T$–*Calculus*. Section 4 describes how logic programming techniques can be used to enhance the fact-retrieval process with deductive techniques. A practical application of our developed methods, a *LogicRobot* to search private advertisements, is presented in Section 5. Related approaches and conclusions are given in Section 6.

2 A Wrapper Language for Web Documents

In this section we describe our information extraction language, the *token-templates*. We assume the reader to be familiar with the concepts of *feature structures* (24) and *unification* (12).

2.1 The Fact Retrieval

We split the process of fact-retrieval into several steps, whereas the first step is the preprocessing of the web page to be analysed. We transform a web page as in Figure 1 into a list of tokens which we will explain in detail in section 2.2. In our existing system (Section 5) this is done by the lexical analyser *FLEX* (16) (by the definition of a *FLEX* grammar to build tokens in extended term notation). We want to emphasize that we are not bound to a special lexical analyser generator tool like *FLEX*, any arbitrary tool can be used as long as it meets the definition of a token.

This methods allows us to apply our techniques not only to *HTML*-documents, but also to any kind of semi-structured text documents. Because we can construct arbitrary tokens, our wrapper language is very flexible to be used in different contexts.

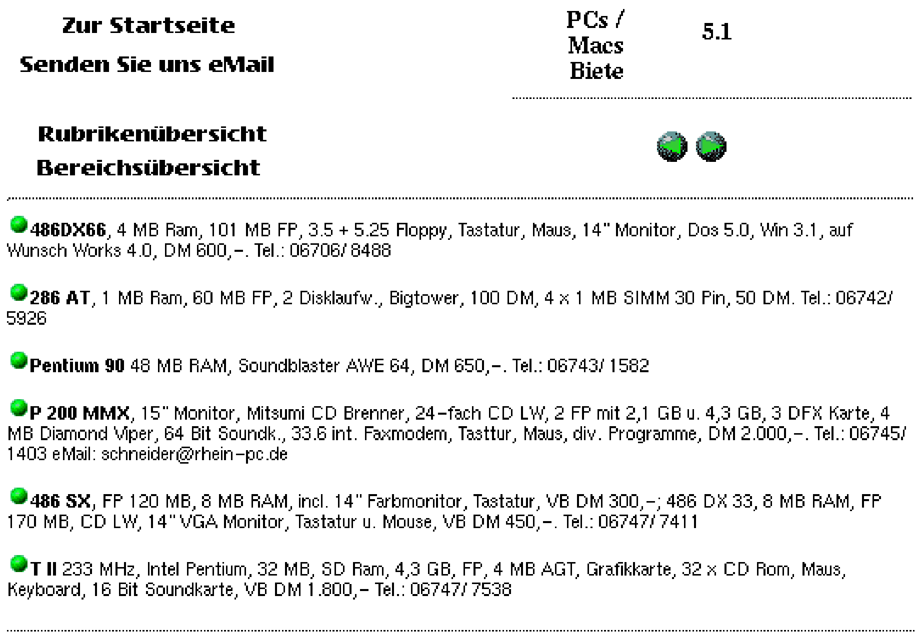
After the source code transformation of the web document, the matching and extraction process takes place. Extraction templates built from tokens and special operators are applied to the tokenized documents. According to the successfull matching of these extraction templates the relevant information is extracted by means of unification techniques and mapped into a relational representation. We will now explain the basic element of our web wrapper language, the *token*.

2.2 The Token

A token describes a grouping of symbols in a document. For example the text `<b>Pentium 90</b>` may be written as the list of tokens:

```
[token(type=html,tag=b), token(type=word,txt='Pentium'),
token(type=whitespace,val=blank), token(type=int,val=90),
token(type=html_end,tag=b)]
```

We call a feature structure (*simple* and acyclic feature structure) a *token*, if and only if it has a feature named `type` and no feature value that consists


Zur Startseite
Senden Sie uns eMail
PCs / Macs Biete
5.1
Rubrikenübersicht
Bereichsübersicht

486DX66, 4 MB Ram, 101 MB FP, 3.5 + 5.25 Floppy, Tastatur, Maus, 14" Monitor, Dos 5.0, Win 3.1, auf Wunsch Works 4.0, DM 600,–. Tel.: 06706/ 8488

286 AT, 1 MB Ram, 60 MB FP, 2 Disklaufw., Bigtower, 100 DM, 4 x 1 MB SIMM 30 Pin, 50 DM. Tel.: 06742/ 5926

Pentium 90 48 MB RAM, Soundblaster AWE 64, DM 650,–. Tel.: 06743/ 1582

P 200 MMX, 15" Monitor, Mitsumi CD Brenner, 24–fach CD LW, 2 FP mit 2,1 GB u. 4,3 GB, 3 DFX Karte, 4 MB Diamond Viper, 64 Bit Soundk., 33.6 int. Faxmodem, Tasttur, Maus, div. Programme, DM 2.000,–. Tel.: 06745/ 1403 eMail: schneider@rhein–pc.de

486 SX, FP 120 MB, 8 MB RAM, incl. 14" Farbmonitor, Tastatur, VB DM 300,–; 486 DX 33, 8 MB RAM, FP 170 MB, CD LW, 14" VGA Monitor, Tastatur u. Mouse, VB DM 450,–. Tel.: 06747/ 7411

T II 233 MHz, Intel Pentium, 32 MB, SD Ram, 4,3 GB, FP, 4 MB AGT, Grafikkarte, 32 x CD Rom, Maus, Keyboard, 16 Bit Soundkarte, VB DM 1.800,– Tel.: 06747/ 7538

Fig. 1. An advertisment web page

of another feature. A feature value may consist of any constant or variable. We write variables in capital letters and constants quoted if they start with a capital letter. Furthermore, we choose a term notation for feature structures (token), that is different from that proposed by Carpenter in (5).

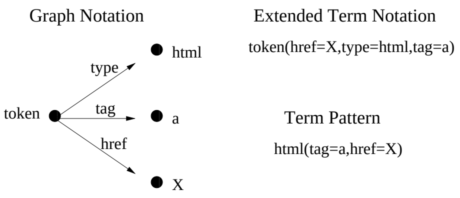


Fig. 2. Token notations

We do not code the features to a fixed argument position, instead we extend the arguments of the annotated term, by the notation `Feature = Value` (extended term notation), this offers us more flexibility in the handling of features. Figure 2 shows the graph notation of a token and our extended term notation of it. In the following we denote a token in extended term notation, simply token.

2.3 Token Matching

In the following let us assume, that an arbitrary web page transformed into a token list is given. The key idea is now to recognize a token or a token sequence in this token list. Therefore we need techniques to match a token description with a token. For feature structures a special unification, the *feature unification* was defined in (23). For our purposes we need a modified version of this unification, the *token-unification*.

Definition 1 (Token-Unification). *Let T_1 and T_2 be token*

$$T_1 = token(m_1 = w_1, m_2 = w_2, \ldots, m_j = w_j)\ j \geq 1$$
$$T_2 = token(m'_1 = w'_1, m'_2 = w'_2, \ldots, m'_k = w'_k)\ k \geq 1$$

Let $A_1 = \bigcup_{i=1}^{j}\{(m_i, w_i)\}$ and $A_2 = \bigcup_{i=1}^{k}\{(m'_i, w'_i)\}$ be the feature-value sets of the token T_1 and T_2. It must hold that $\{m_1, \ldots, m_j\} \subseteq \{m'_1, \ldots, m'_k\}$. If this is not the case, we call T_1 and T_2 not token-unifiable, $\not\sqcup$. Let $F = \{m \mid (m, w) \in A_1\}$ be the set of features T_1 and T_2 have in common. The terms T'_1 and T'_2 are defined as follows:

$$T'_1 := token(m_1 = w_1, \ldots, m_n = w_n)$$
$$T'_2 := token(m_1 = w'_1, \ldots, m_n = w'_n)$$
$$\textit{with } m_i \in F \wedge (m_i, w_i) \in A_1 \wedge (m_i, w'_i) \in A_2 \wedge 1 \leq i \leq n \wedge n = |F|$$

T_1 and T_2 are token-unifiable iff *T'_1 is unifiable with T'_2. The most general unifier (mgU) σ of T_1 and T_2 is the mgU of T'_1 and T'_2 wrt. the usual definition (12). We write $T_1 \sqcup_\sigma T_2$* iff *T_1 is token-unifiable with T_2 and σ is the mgU of the unification from T'_1 with T'_2.* ■

The motivation for this directed unification [1] is to interpret the *left* token to be a pattern to match the *right* token. This allows us to set up feature constraints in a easy way, by simply adding a feature to the *left* token. On the other hand we can match a whole class of tokens, if we decrease the feature set of the *left* token to consist only of the *type* feature. For example:

- *token(type=word)* $\sqcup_\sigma$ *token(type=word, txt='Pentium')* with $\sigma = []$
- *token(type=word, int=X)* $\not\sqcup_\sigma$ *token(type=word,txt='Pentium')*
- *token(tag=X,type=html,href=Y)* $\sqcup_\sigma$ *token(type=html, tag=a, href='http://www.bmw.de')* with $\sigma = [X/a, Y/'http://www.bmw.de']$

For ease of notation we introduce an alternative notation t^k for a token of type k (`type` feature has value k), that is given by k or $k(f_1 = v_1, f_2 = v_2, \ldots, f_n = v_n)$ with f_i and v_i are the features and values of t^k where n is the number of features of t^k. We call this notation *term-pattern* and define a transformation $\mathcal{V}$ on *term-patterns* such that $\mathcal{V}$ transforms the *term-pattern* into the corresponding token. For example $\mathcal{V}(word(len = 5, text = X))$ gives us the token $token(type = word, len = 5, text = X)$. This transformation exchanges the functor of the *term-pattern*, from type k to *token* and adds the argument $type = k$ to the arguments.

Now we can define the basic match operation on a *term-pattern* and a token:

[1] In the sense that the feature set of the *left* token must be a subset of the feature set of the *right* token.

Definition 2 (Term-Match). *Let t^k be a term-pattern and T a token in extended term notation. The term-pattern t^k matches the token T, $t^k \sqsubset_\sigma T$,* iff *$\mathcal{V}(t^k)$ is token-unifiable with T. The term-match is defined as follows:*

$$t^k \sqsubset_\sigma T \iff \mathcal{V}(t^k) \sqcup_\sigma T \text{ where } \sigma \text{ is mgU.}$$

■

For the demonstration of the term-match operation, consider the three examples mentioned above and the following modification:

- *word* $\sqsubset_\sigma$ *token(type=word, txt='Pentium')* with $\sigma = []$
- *word(int=X)* $\not\sqsubset_\sigma$ *token(type=word,txt='Pentium')*
- *html(href=Y)* $\sqsubset_\sigma$ *token(type=html, tag=a, href='http://www.bmw.de')* with $\sigma = [Y/'http://www.bmw.de']$

2.4 Token Pattern

If we interpret a token to be a special representation of text pieces, the definition of term-matching allows us to recognize certain pieces of text and extract them by the process of unification. This means the found substitution σ contains our extracted information.

But yet we are not able to match sequences of tokens in a tokenized web page. Therefore we define the syntax of *token-pattern*, which will build our language to define templates for the information extraction from web documents.

The language of *token-patterns* is built on a similiar concept as regular expressions are. The difference is, that the various iteration operators are defined on tokens. Beside these basic operators we define *greedy* and *moderate* operators. These two operator classes determine the enumeration order of matches. *Greedy* Operators are: $?, +$ and $*$. *Moderate* Operators are: $!, -$ and $\#$. For example a *token-pattern* like $*word$, matches zero or arbitrary many tokens of type word, but the first match will try to match as many tokens of type word as possible (*greedy*). Whereas the pattern $\#word$ will try in its first attempt to match as less tokens as possible (*moderate*). This makes sense if a pattern is just a part of a larger conjunction of patterns. Another advantage is given by the use of unification, which in fact allows us with the later described concept of recursive *token-templates* to recognize context sensitive languages.

Next we give an informal definition [2] for the semantics of *token-pattern* (see Figure 3), and assume that a tokenized document D is given. A match of a *token-pattern* p on D, $p \rhd D$, returns a set of triples (MS, RS, σ), where MS is the matched token sequence, RS is the rest sequence of D and σ is the mgU of the token unifications applied during the matching process.

[2] see (27) for a detailed formal definition.

expression	semantics
term-pattern	If $p \sqsubset_\sigma D(1)$ is true, then the matched sequence is the list with exactly one element $D(1)$ and RS is D without the first element. $D(n)$ denotes the n-th element of the sequence D.
$?p_1$	Matches once or never the pattern p_1. First the match of p_1 then the empty match sequence is enumerated.
$!p_1$	Matches once or never the pattern p_1. First the empty match sequence then the match of p_1 is enumerated.
$+p_1$	Matches arbitrary often but at least once the pattern p_1. Uses a decreasing enumeration order of the matches according to their length. Starting with the longest possible match.
$-p_1$	Matches arbitrary often but at least once the pattern p_1. Uses a increasing enumeration order of the matches according to their length. Starting with the shortest possible match.
$*p_1$	Matches arbitrary often the pattern p_1. Uses a decreasing enumeration order of the matches according to their length. Starting with the longest possible match.
$\#p_1$	Matches arbitrary often the pattern p_1. Uses a increasing enumeration order of the matches according to their length. Starting with the shortest possible match.
$not(t_1, \ldots, t_n)$	The *not* operator matches exactly one token t in D, if no $t_i \in \{t_1, \ldots, t_n\}$ exists, such that $t_i \sqsubset_\sigma t$ holds. The token $t_1 \ldots t_n$ are excluded from the match.
$times(n, t)$	Matches exactly n tokens t.
any	Matches an arbitrary token.
$once(p_1)$	The *once* operator 'cuts' the set of matched tokens by p_1 down to the first match of p_1. Useful if we are only interested in the first match and not in all alternative matches defined by p_1.
$X = p_1$	Unification of X and the matched sequence of p_1. Only successful if p_1 is successful and if MS of p_1 is unifiable with X.
$p_1 \, and \, p_2$	Only if p_1 and p_2 both match successfully, this pattern succeeds. The matched sequence of p_1 and p_2, is the concatenation of MS of p_1 and MS of p_2.
$p_1 \, or \, p_2$	p succeeds if one of the pattern $p1$ or p_2 successfully matched. The matched sequence of p is either the matched sequence of p_1 or p_2. The *and* operator has higher priority than the *or* operator, (e.g. $a\ and\ b\ or\ c \equiv (a\ and\ b)\ or\ c$)

Fig. 3. The basic token pattern language

We emphasize, that we compute all matches and do not stop after we have found one successful match, though this can be achieved by the use of the *once* operator.

```
<P><IMG SRC=img/bmp_priv.gif><B>286 AT</B>,
1 MB Ram, 60 MB FP, 2 Disklaufw., Bigtower, 100 DM, 4 x 1 MB SIMM 30
Pin, 50 DM. Tel.: 06742/ 5926
<P><IMG SRC=img/bmp_priv.gif><B>Pentium 90</B> 48 MB RAM, Soundblaster
AWE 64, DM 650,-. Tel.: 06743/ 1582
```

Fig. 4. HTML source code of an online advertisment

$$\begin{array}{l} \#any\ and\ html(tag = img)\ and\ html(tag = b) \\ and\ Item = *not(html\_end(tag = b))\ and\ html\_end(tag = b) \\ and\ once(Description = *not(html(tag = p))) \end{array}$$

Fig. 5. Token-pattern for advertisment information extraction

Let us have a closer look at the source code of the advertisment web page shown in Figure 4 and the corresponding token-pattern 5. This *token-pattern* extracts the item name of the offered object (*Item*) and the description (*Description*) of the item. For this small example our set of matches consists of a set with two tuples, where we will leave out the matched sequence MS and the rest sequence RS, because we are only interested in the substitutions σ of each match:

{[$Item/'$*286 AT*$'$, $Description/'$*1 MB Ram, 60 MB FP, 2 Disklaufw., Bigtower, 100 DM, 4 x 1 MB SIMM 30 Pin, 50 DM. Tel.: 06742/ 5926'*],
[$Item/'$*Pentium 90*$'$, $Description/'$*48 MB RAM, Soundblaster AWE 64, DM 650,-. Tel.: 06743/ 1582*$'$]}

2.5 Token-Templates

A *token-template* defines a relation between a tokenized document, extraction variables and a *token-pattern*. Extraction variables are those variables used in a *token-pattern*, which are of interest due to their instantiation wrt. to the substitutions obtained from a successful match. Extraction variables *hold* the extracted information obtained by the matching process of the *token-pattern* on the tokenized document.

Definition 3 (Token-Template). *Let p be a token-pattern, D an arbitrary tokenized document and $v_1, \ldots, v_n \in \mathcal{V}ar(p)$ variables in p. For $v_1, \ldots, v_n$ we write $\boldsymbol{v}$ and $\boldsymbol{v}_\sigma$ for applying the substitution σ to $\boldsymbol{v}$. A token-template r is defined as follows:*

$$r(D, \boldsymbol{v}, p) := \{(D, \boldsymbol{v}_\sigma, p_\sigma) | (MS, RS, \sigma) \in p \rhd D\}$$

Template definitions are written as: $\underline{template}\; r(D, v_1, \ldots, v_n) := p$
r is called the template name, $\boldsymbol{v}_\sigma$ is the extraction tupel and $v_1, \ldots, v_n$ are called extraction variables. ■

Consider the case where we want to extract all links from a web page. The following *token-template* will do the job:

$$\begin{aligned}&\underline{template}\; link(D, Link, Desc) := \#any\\ &\qquad and\; html(tag = a, href = Link)\; and\; Desc = +not(html\_end(tag = a))\end{aligned}$$

We now extend the *token-templates* with the following concepts in order, to be able to match more sophisticated syntactic structures:

Template Alternatives: To gain more readability for template definitions we enhanced the use of the *or* operator. Instead of using the *or* operator in a *token-pattern* like in the template $\underline{template}\; t(D, \boldsymbol{v}) := \boldsymbol{v} = (p_1\; or\; p_2)$ we can alternatively define two templates:

$$\begin{aligned}&\underline{template}\; t_1(D, \boldsymbol{v_1}) := \boldsymbol{v_1} = p_1\\ &\underline{template}\; t_2(D, \boldsymbol{v_2}) := \boldsymbol{v_2} = p_2\end{aligned}$$

where the templates t_1 and t_2 have the same name. In fact this does not influence the calculation of the extraction tuples, because we can easily construct this set by the union of t_1 and t_2.

Code Calls: A very powerful extension of the *token-pattern* language is the integration of function/procedure calls within the matching process. We named this extension, *code calls*. A code call may be any arbitrary boolean calculation procedure that can be invoked with instantiated *token-pattern* variables or unbound variables that will be instantiated by the calculation procedure. The following example demonstrates the use of a code call to an database interface function *db*, that will check if the extracted *Name* can be found in the database. On success it will return *true* and instantiates *Birth* to the birthday of the person, otherwise the match fails. In this example we will leave out the *token-pattern* for the recognition of the other extraction variables and will simply name them p_1 to p_3 :

$$\begin{aligned}&\underline{template}\; person(D, Name, Str, Tel, Birth) := \#any\; and\\ &\qquad Name = p_1\; and\; \{db(Name, Birth)\}\; and\; Str = p_2\; and\; Tel = p_3\end{aligned}$$

Especially the use of logic programs as code to be called during the matching process, can guide the information extraction with intelligent methods.

Template Calls & Recursive Templates: To recognize hierachical syntactic structures in text documents it is obvious to use recursive techniques. Quite often the same subpattern has to be used in a template definition, therefore we extended the *token-pattern* by template calls. A template call may be interpreted as an inclusion of the *token-pattern* associated with the template to be called. For example the first example template matches a HTML table row existing of 3 columns, where the first two are text columns and the third contains price information. The terms set in squared brackets function as template calls. Repeated application of this pattern, caused by the sub pattern $\#any$, gives us all table entries. The second template demonstrates a recursive template call. That template matches correct groupings of parenthesises:

$$
\begin{aligned}
&\underline{template}\; table\_row(D, Medium, Label, Price) := (\,\#any\\
&\qquad and\; html(tag = tr)\\
&\qquad and\; [text\_col(Medium), text\_col(Label), price\_col(Price)]\\
&\qquad and\; html\_end(tag = tr))
\end{aligned}
$$

$$
\begin{aligned}
&\underline{template}\; correct\_paren(D, A) :=\; A = (\,paren\_open\; and\\
&\qquad (*word\; or\; *\,word\; and\; [correct\_paren(\_)]\; and\; *\,word\;)\\
&\qquad and\; paren\_close\;)
\end{aligned}
$$

For a more detailed description of the *token-template* language the reader is refered to (27).

3 Logic Programs and Token-Templates

In this section we will explain how *token-templates* can be merged with logic programs (LP's). The basic idea of the integration of *token-templates* and LP's is to extend a logic programm with a set of *token-templates* (extended LP's), that are interpreted as special program clauses. The resulting logic program can then answer queries about the contents of one or more web documents. Intuitively *token-templates* provide a set of facts to be used in logic programs. Extended LP's offer the possibility to derive new facts based on the extracted facts from the WWW. From the implementational point of view these *token-template* predicates may be logical programs or modules that implement the downloading of web pages and the token matching. From the theoretical point of view we consider these template sets to be axiomatizations of a theory, where the calculation of the theory (the facts) are performed by a background reasoner.

In the following we refer to *normal logic programs* when we talk about logic programs. We assume the reader to be familiar with the fields of *logic programming* (19) and *theory reasoning* (2) (25).

3.1 Template Theories

In the context of first order predicate logic (PL1) we interpret a set of *token-templates* to be an axiomatisation of a theory. A *token-template theory* $\mathcal{T}_T$ is the set of all template ground atoms, that we obtain by applying all templates in T. For example, consider the template set $\{t(D, v, p)\}$. Assume p to be an arbitrary *token-pattern* and v an extraction tupel. A *template theory* for T is given by $\mathcal{T}_{\{t(D,v,p)\}} := \{t(D, v', P')|(D, v', p') \in t(D, v, p)\}$. This interpretation of *token-templates* associates a set of ground unit clauses with a given set of *token-templates*. The formal definition is as follows:

Definition 4 (Template-Theory, $\mathcal{T}_\mathbf{T}-$Interpretation, $\mathcal{T}_\mathbf{T}-$Model). *Let T be a set of token-templates: $T = \{t_1(D, \boldsymbol{v}_1, p_1), t_2(D, \boldsymbol{v}_2, p_2), \ldots, t_n(D, \boldsymbol{v}_n, p_n)\}$. A token-template theory $\mathcal{T}_T$ for T is defined as follows:*

$$G(t(D, \boldsymbol{v}, p)) = \{t(D, \boldsymbol{v}', p')|D \text{ is a ground term and } (D, \boldsymbol{v}', p') \in t(D, \boldsymbol{v}, p)\}$$

$$\mathcal{T}_T = \bigcup_{i=1}^{n} G(t_i(D, \boldsymbol{v}_i, p_i)) \quad \text{with } t_i(D, \boldsymbol{v}_i, p_i) \in T$$

Let P be a normal logic program with signature Σ, such that Σ is also a signature for $\mathcal{T}_T$:

- *A $\Sigma-$Interpretation $\mathcal{I}$ is a $\mathcal{T}_T$–$\Sigma-$Interpretation* iff $\mathcal{I} \models \mathcal{T}_T$.
- *A Herbrand $\mathcal{T}_T$–$\Sigma-$Interpretation is a $\mathcal{T}_T$–$\Sigma-$Interpretation, that is also a herbrand interpretation.*
- *A $\mathcal{T}_T$–$\Sigma-$Interpretation $\mathcal{I}$ is a $\mathcal{T}_T-$Model for P* iff $\mathcal{I} \models P$.
- *Let X be a clause, wrt. Σ. X is a logic $\mathcal{T}_T$–Consequence from P, $P \models_{\mathcal{T}_T} X$,* iff *for all $\mathcal{T}_T$–$\Sigma-$Interpretation $\mathcal{I} : \mathcal{I} \models P$ follows $\mathcal{I} \models X$.*

■

Consider a *token-template* `advertise` with the *token-pattern* given in Figure 4 and the extraction variables `Item` and `Description` for the example web source code shown in Figure 1. The corresponding *template theory* for the template `advertise` is the set:

{ *advertise*('*286 AT*',' *1 MB Ram, 60 MB FP, 2 Disklaufw., Bigtower, 100 DM, 4 x 1 MB SIMM 30 Pin, 50 DM. Tel.: 06742/ 5926*'),
advertise('*Pentium 90*',' *48 MB RAM, Soundblaster AWE 64, DM 650,-. Tel.: 06743/ 1582*') }

3.2 The $\mathcal{T}_\mathbf{T}$–Calculus

So far we have shown when a formula is a logical consequence from a logic program and a *template theory*. This does not state how to calculate or check if a formula is a logical consequence from an *extended logic program*. Therefore we have to define a calculus for *extended logic programs*.

Definition 5 ($\mathcal{T}_\mathrm{T}$–Derivation). *Let $\mathcal{K}$ be a sound and answer-complete calculus for normal logic programs and $\vdash$ is the derivation defined by $\mathcal{K}$. Let P be a normal logic program, T a set of token-templates and $\mathcal{T}_T$ the template theory for T. A query $\exists\, Q$ with calculated substitution σ is $\mathcal{T}_T$–derivable from P, $P \vdash_{\mathcal{T}_T} Q\sigma$,* iff *$Q\sigma$ is derivale from $P \cup \mathcal{T}_T$, $P \cup \mathcal{T}_T \vdash Q\sigma$. A calculus $\mathcal{K}$, with $\mathcal{T}_T$–Derivation is called $\mathcal{T}_T$–Calculus.* ■

Theorem 1 (Soundness). *Let $\mathcal{K}$ be a $\mathcal{T}_T$–Calculus and $\vdash_{\mathcal{T}_T}$ the derivation relation defined by $\mathcal{K}$. Let T be a set of token-templates, $\mathcal{T}_T$ the template-theory for T and Q a query for a normal program P. Further let σ be a substitution calculated by $\vdash_{\mathcal{T}_T}$. Then $\forall\, Q : P \vdash_{\mathcal{T}_T} Q\sigma \Rightarrow P \models_{\mathcal{T}_T} \forall\, Q_\sigma$* □

Theorem 2 (Completeness). *Let $\mathcal{K}$ be $\mathcal{T}_T$–Calculus and $\vdash_{\mathcal{T}_T}$ the derivation relation defined by $\mathcal{K}$. Let T be a set of token-templates, $\mathcal{T}_T$ the template-theory for T and Q a query for a normal program P. Let θ be a correct answer for Q, σ a calculated answer and γ a substitution.*
Then $\forall\, \theta : P \models_{\mathcal{T}_T} Q\theta \Rightarrow P \vdash_{\mathcal{T}_T} Q\sigma$ where $\theta = \sigma\gamma$ □

Proof (Soundness and Completness). Let $\mathcal{K}$ be a $\mathcal{T}_T$*–Calculus* and $\vdash_{\mathcal{T}_T}$ the derivation relation defined by $\mathcal{K}$. Let T be a set of templates , $\mathcal{T}_T$ the template theory of T and Q a query on the normal program P. Let σ be a calculated substitution for Q such that:

$$\begin{array}{ll} P \vdash_{\mathcal{T}_T} Q\sigma & \\ \Leftrightarrow P \cup \mathcal{T}_T \vdash Q\sigma & \textit{def. 5} \\ \Leftrightarrow P \cup \mathcal{T}_T \models \forall\, Q\sigma & \textit{sound/completness of } \vdash \\ \Leftrightarrow P \models_{\mathcal{T}_T} \forall\, Q\sigma & \end{array}$$

To prove: $P \cup \mathcal{T}_T \models \forall\, Q\sigma \Leftrightarrow P \models_{\mathcal{T}_T} \forall\, Q\sigma$

$'' \Rightarrow''$:

$$\begin{array}{ll} P \cup \mathcal{T}_T \models \forall\, Q\sigma & \\ \Leftrightarrow \forall\, \mathcal{I} : \mathcal{I} \models P \cup \mathcal{T}_T \Rightarrow \mathcal{I} \models \forall\, Q\sigma & \textit{def. logical consequence} \\ \Leftrightarrow \forall\, \mathcal{I} : (\mathcal{I} \models P \text{ and } \mathcal{I} \models \mathcal{T}_T) \Rightarrow \mathcal{I} \models \forall\, Q\sigma & \textit{def. interpretation} \end{array}$$

$'' \Leftarrow''$:

$$\begin{array}{ll} P \models_{\mathcal{T}_T} \forall\, Q\sigma & \\ \Leftrightarrow \forall\, \mathcal{T}_T\textit{–Interpret.}\, \mathcal{I} : (\mathcal{I} \models P \Rightarrow \mathcal{I} \models \forall\, Q\sigma) & \textit{def. } \mathcal{T}_T\textit{–Consequence} \\ \Leftrightarrow \forall \mathcal{I} : \mathcal{I} \models \mathcal{T}_T \Rightarrow (\mathcal{I} \models P \Rightarrow \mathcal{I} \models \forall\, Q\sigma) & \textit{def. } \mathcal{T}_T\textit{–Interpretation} \end{array}$$

$$\forall\, \mathcal{I} : (\mathcal{I} \models P \text{ and } \mathcal{I} \models \mathcal{T}_T) \Rightarrow \mathcal{I} \models \forall\, Q\sigma \Leftrightarrow \\ \forall\, \mathcal{I} : \mathcal{I} \models \mathcal{T}_T \Rightarrow (\mathcal{I} \models P \Rightarrow \mathcal{I} \models \forall\, Q\sigma)$$

$$\forall\, \mathcal{I} : (\mathcal{I} \models P \text{ and } \mathcal{I} \models \mathcal{T}_T) \Rightarrow \mathcal{I} \models \forall\, Q\sigma \Leftrightarrow \\ \forall\, \mathcal{I} : (\mathcal{I} \models \mathcal{T}_T \text{ and } \mathcal{I} \models P) \Rightarrow \mathcal{I} \models \forall\, Q\sigma$$

q.e.d.

In Figure 6 an example $\mathcal{T}_T$*–Derivation* based on the SLD-Calculus (14) is shown. The calculation of the *template theory* is done by a theory box (2), this may be any arbitrary calculation procedure, that implements the techniques needed for *token-templates*. Furthermore this theory box has to decide if a template predicate, like `institute('http://www.uni-koblenz.de',Z,P)` can be satisfied by the calculated theory.

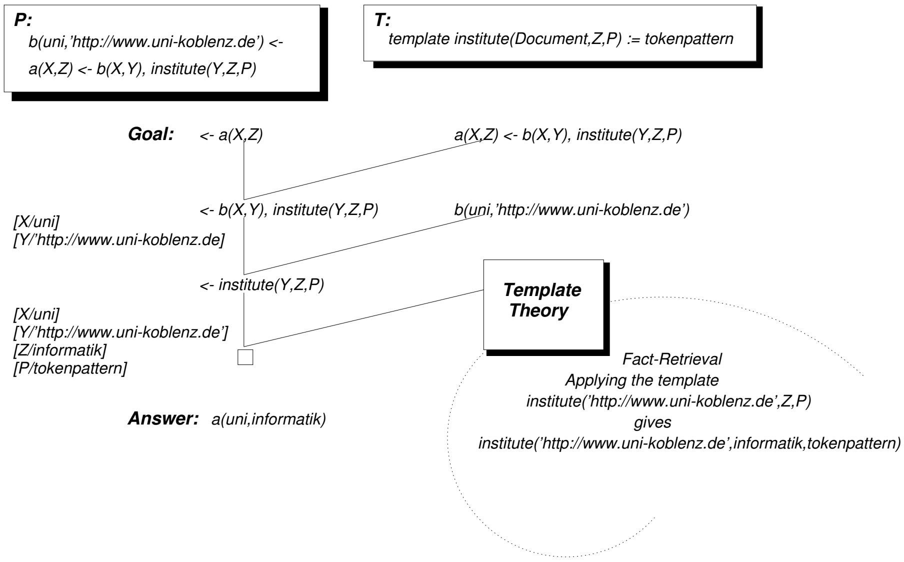


Fig. 6. $SLD - \mathcal{T}_T$*–Derivation*

4 Deductive Techniques for Intelligent Web Search

Logic programming and deduction in general offer a wide variety to guide the web search and fact-retrieval process with intelligent methodes and inference processes. This section describes some of these techniques.

4.1 Deductive Web Databases

Assume we know two web pages of shoe suppliers, whose product descriptions we want to use as facts in a deductive database. Additionally we are interested in some information about the producer of the product, his address and telephon number that can be retrieved from an additional web page. Therefore we define two *token-templates*, *price_list* and *address*. To simplify notation we leave out the exact *token-pattern* definitions.

The following small deductive database allows us to ask for articles and to derive new facts that provide us with information about the product and the producer. We achieve this by the two rules *article* and *product*, which extract the articles offered at the web pages and will derive new facts about the article and the producer.

$\underline{template}$ $price\_list(Document, Article, Price, ProducerUrl) = P_1$
$\underline{template}$ $address(Document, Producer, Str, Tel, City) = P_2$

$web\_page('ABC-Schuhe', http://www.abcshoes.com/offer.html) \leftarrow$
$web\_page('Schuhland', http://www.shland.com/angebot.html) \leftarrow$

$article(Supplier, Article, Price, ProducerUrl) \leftarrow$
$\quad web\_page(Supplier, Document),$
$\quad price\_list(Document, Article, Price, ProducerUrl, Pattern)$

$product(Supplier, Producer, Article, Price, Str, Tel, City) \leftarrow$
$\quad article(Supplier, Article, Price, ProducerUrl),$
$\quad address(ProducerUrl, Supplier, Str, Tel, City, Pattern)$

Here are some example queries to demonstrate the use of the deductive web database:
Select all products with article name "*Doc Martens*" that cost less than 100:
$\leftarrow Article = "Doc\ Martens",$
$product(Supplier, Article, Producer, Price, Str, Tel, City), Price < 100$

Select all products offered at least by two suppliers:
$\leftarrow product(Supplier1, Producer, Article, Price1, Str1, Tel1, City1),$
$product(Supplier2, Producer, Article, Price2, Str2, Tel2, City2),$
$Supplier1 \backslash= Supplier2$

4.2 Optimizing Web Retrieval

The following example shows how a query optimization technique proposed by Levy (18) can be implemented and used in *extended logic programs*. To avoid the fetching of senseless web pages and starting a *fact-retrieval* process we know for certain to fail, Levy suggests the use of source descriptions. For the fact retrieval from the WWW this might offer a great speed up, because due to the network load the fetching of web documents is often very time intensive. In the context of *extended logic programs*, we can easily apply these methods, by the definition of rules, whose body literals define constraints on the head arguments expressing our knowledge about the content of the web pages. The following example illustrates these methods:

$offer('http://www.autos.com/biete.html', Price, Country) \leftarrow$
$\quad Price > 20000, Price < 40000, Country = 'Deutschland'$
$offer('http://www.cars.com/sells.html', Price, Country) \leftarrow$
$\quad Price > 40000, Price < 60000, Country = 'USA'$
$product(Car, Price, Country) \leftarrow$

$offer(WebPage, Price, Country),$
$template\_cars(WebPage, Price, Country)$

Assuming we are interested in american cars that costs 50000 dollars, the query `product(C,50000,'USA')` will retrieve the according offers. Because of the additional constraints on the price and the country given in the body of the rule `offer`, the irrelevant web page with german car offers is left out. By simple methods, provided by the logic programming paradigm for free, we are able to guide the search and fact retrieval in the world wide web based on knowledge representation techniques (3) and we are able to speed up the search for relevant information.

4.3 Conceptual Reasoning

Many information systems lack of the ability to use a conceptual background knowledge to include related topics of interest to their search. Consider the case that a user is interested in computer systems that cost less than 1000 DM. It is obvious that the system should know the common computer types and descriptions (e.g. IBM, Toshiba, Compaq, Pentium, Notebook, Laptop) and how they are conceptually related to each other. Such knowledge will assist a system in performing a successful search. One way to represent such knowledge is by concept description languages or in general by means of knowledge representation techniques. In the last few years it showed up that logic is a well suited analytic tool to represent and reason about represented knowledge. Many formalisms have been implemented using logic programming systems, for example *PROLOG*.

For example a simple relation is_a can be used to represent conceptual hierachies to guide the search for information. Consider the following small knowledge base:

$$\begin{aligned}
notebook('ThinkPad') &\leftarrow \\
notebook('Satellite') &\leftarrow \\[1em]
is_a(notebook, computer) &\leftarrow \\
is_a(desktop, computer) &\leftarrow \\
is_a(X, notebook) &\leftarrow notebook(X) \\[1em]
relevant(Q, Z) &\leftarrow is_a(Z, Q) \\
relevant(Q, Z) &\leftarrow is_a(Y, Q), relevant(Y, Z)
\end{aligned}$$

Assume our general query to search for computers less than 100 DM is splitted into a sub query like $\leftarrow relevant(computers, X)$ to our small example knowledge base. The query computes a set of answers:
$\theta = \{[X/notebook], [X/desktop], [X/'ThinkPad'], [X/'Satellite']\}$.

This additional inferred query information θ can be used in two different ways: first we use it to search for new web pages, e.g. by querying standard search engines with elements of θ as search keywords. On the returned candidate pages further extended logic programs can be applied to extract facts. Second, we enhance the information extraction process with the derived information θ by reducing the constraints on special token features in the token-templates to be applied, e.g. *word(txt=Q) or word(txt=*θ_1*) or ... or word(txt=*θ_n*)* where θ_i are computed answers and Q is the original object to search for. That means we include to the search all sub concepts (e.g. *computer* $\rightarrow$ *notebook* $\rightarrow \ldots$) or instances (e.g. $'ThinkPad'$) of the query concept.

5 The LogicRobot

This section will give a short overview of one application we implemented using the described methods and techniques described so far.

5.1 The Problem

Very often web pages are organized by a chain of links the user has to follow to finally reach the page he is interested in. Or the information the user wants to retrieve is splitted into many pages. In both cases the user has to visit many pages to finally reach the intended page or to collect data from them. To do this manually is a very exhausting and time consuming work and furthermore it is very difficult for the user to take comparisons between the information offered on the various web pages. Therefore an automatic tool to follow all links, to collect the data and to provide the possibilty to compare the retrieved information is needed to free the user from this annoying work.

We call web information systems based on *logic programs* and *token-templates LogicRobots*. Similiar to physical robots they navigate autonoumasly through their enviroment, the web. According to their ability to analyze and reason on web page contents and the incorporation of knowledge bases they are able to percept their environment, namely what's on a web page. Due to the underlying logic program and the used AI techniques, e.g. knowledge representation, default reasoning etc., they act by collecting facts or follow up more promising links.

The problem we focused on was to build a *LogicRobot* for a web vendor offering private advertisments. Some of the offered columns forces the user to follow about 80 to 100 links to see all advertisements, which is of course not very user-friendly. A more elegant way would be to offer a web formular where the user can specify the column or columns to be searched either by entering a specific name or a keyword for a column name, a description of the item he is searching for, a price constraint like less, greater or equal to and finally a pattern of a telefon number to restrict the geographical area to be searched. Figure 7 shows the *LogicRobot* web interface for this special task and a sample result page is shown in Figure 8.

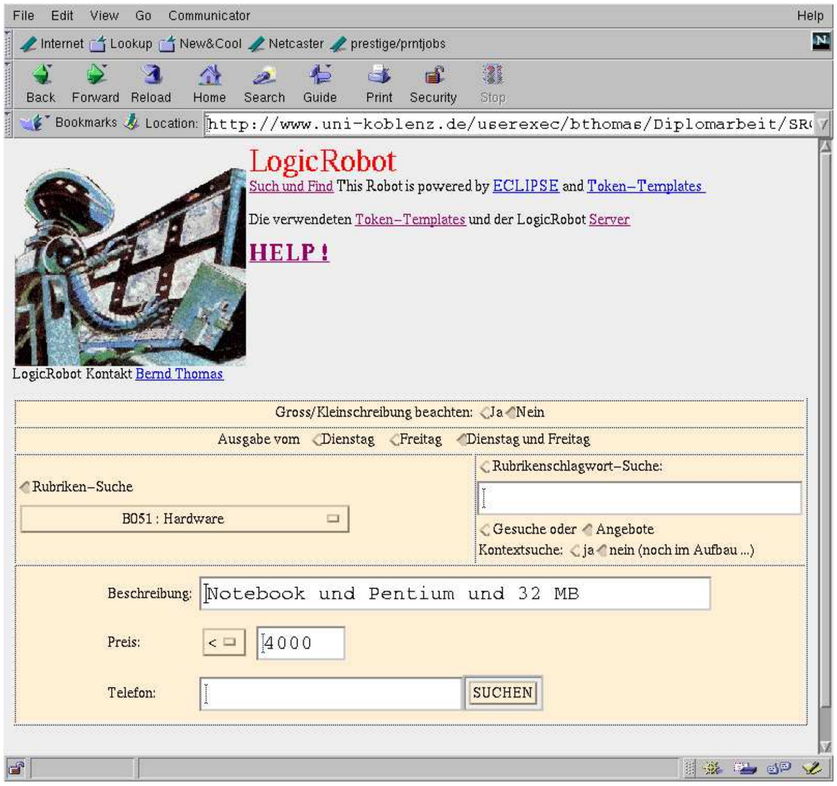


Fig. 7. The LogicRobot web interface

5.2 Implementational Notes

The *LogicRobot* for the search of advertisments is based on the logic programming library *TXW3* (27) that implements the techniques presented in this paper using *ECLIPSE*-Prolog (11). *ECLIPSE* supports modularized logic programming, so we modularized the architecture of the *LogicRobot* into two main modules, the first module containig all needed token-template definitions and the second the prolog program implementing the appropriate template calls, the evaluation of the price constraints and further control operations. This prolog module is executed by the *CGI* mechanism and communicates with the local *http daemon* via *stdin/stdout* ports. So there is no additional server programming or network software needed to setup a search engine based on *extended logic programs*.

By only 5 template definitions and approx. 200 lines of prolog code we implemented this *LogicRobot*. The tests we carried out with our application are very promising. For example the query answering time, which contains fetching, tokenizing, extracting and comparing is beneath 2 minutes for 100 web pages of advertisements (Figure 1) . We think this is a very promising way for a domain specific search tool, that can be easily extended by AI methods, that offers a flexible and fast configurability by means of declarative definitions (e.g. using *PROLOG*) and most important this concept of *LogicRobots* can be applied to various information domains on the World Wide Web.

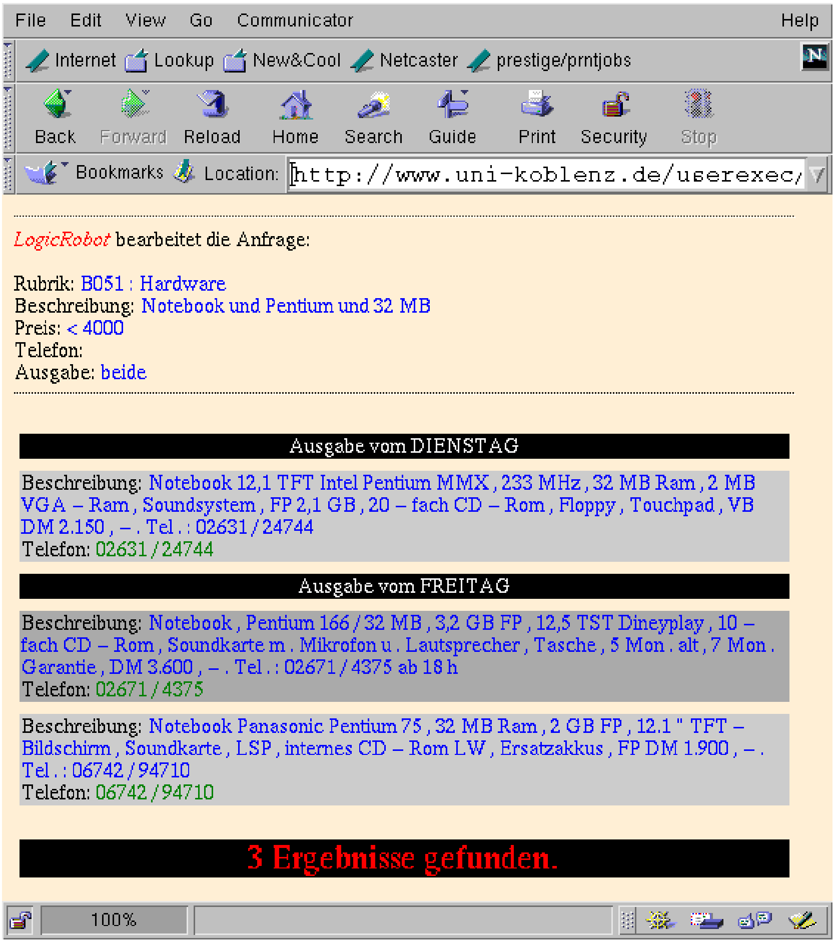


Fig. 8. Query result page

6 Related Work and Conclusion

We presented the *token-template* language for the IE from semistructured documents, especially from web pages. We showed how our wrapper language can be merged with logic programs and gave a formal definition for the extension of an arbitrary answer complete first order logical calculus with *template theories*. In conjunction with the area of logic programming and deductive databases we can use these wrapper techniques to obtain inferences or new deductively derived facts based on information extracted from the WWW. Furthermore these methods can be used to build intelligent web information systems, like *LogicRobots*, that gain from the closely related areas like deductive databases, knowledge representation or logic programming based AI methods. We also showed how already developed query optimization techniques (Section 4.2), can easily be integrated into our approach. Our methods have been successfully integrated and used in the heterogeneous information system *GLUE* (20) to access web data and integrate it into analytical and reasoning processes among heterogeneous data sources (e.g. relational databases, spreadsheets, etc.). In addition to our theoretical work we also implemented a logic programming library *TXW3* that provides the language of *token-templates* and various other logic modules to program *LogicRobots* for the WWW.

Several web information systems have been developed in the last few years. One class of applications called *Softbots*, which are domain specific automated search tools for the WWW, searching autonomously for relevant web pages and user requested informations, are similiar to our concept of a *LogicRobot*. But such existing systems like *Ahoy!* (22) or *Shopbot* (7) use either tailored extraction techniques (*Ahoy!*) that are very domain specific or their extraction techniques are based on highly restrictive assumptions about the syntactical structure of a web page (*Shopbot*). Both systems do not follow the concept of a general purpose extraction language like *token-templates* are. *Token-templates* are applicable to any kind of semistructured text documents, and hence not restricted to a specific domain.

Systems like *IM* (17) or *W3QS* (13) also provide means to query web information sources. Though Levy et. al. also choose a relational data model to reason about data, and show several techniques for source descriptions or constructing query plans, they leave the problem of information extraction undiscussed in their work. We showed solutions for both the extraction of facts and reasoning by extended logic programs. The *W3QS* system uses a special web query language similiar to the relational database query language *SQL*. *W3QS* uses enhanced standard SQL commands, e.g. by additional external unix program calls or HTML related commands. Though an additional construction kit for information extraction processes is given, this seems to be focussed only on the detection of hyper links and their descriptions. The concept of database views for web pages is also introduced, but no information about recursive views is provided, whereas extended logic programs offer these abilities.

Heterogeneous information systems, like *DISCO* (28), *GLUE* (20), *HERMES* (26), *Infomaster* (8) or *TSIMMIS* (6) all use special mediator techniques to access web information sources among other data sources. These systems use their own mediator model (language) to interface with the special data source wrappers. The system *HERMES* for example is based on a declarative logical mediator language and therefore is similiar to our approach using extended logic programs as mediators and *token-templates* as special wrapper language. The advantage of our presented approach is simply, that the above named systems except *TSIMMIS* and *GLUE* do not incorporate a general purpose wrapper language for text documents. Additionally work on the expressive power of the mediator languages and the used wrapper techniques of the other systems is of interest.

Different from the template based extraction languages described in (10) and (4) or the underlying language used in the wrapper construction tool by Gruser et. al. (9), *token-templates* incorporate the mighty concepts of recursion and *code calls*. These concepts allow the recognition and extraction of arbitrary hierachical syntactic structures and extends the matching process by additional control procedures invoked by code calls. Especially logic programs used as *code calls* can guide the extraction process with a manifold of AI methods in general.

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