

# Fuzzy Classification of Web Reports with Mining from Texts with Linguistic Annotations

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## Abstract

In this paper we present a fuzzy system, which provides a fuzzy classification of textual web reports. Our approach is based on usage of third party linguistic analyzers, our previous work on web information extraction and fuzzy inductive logic programming. Main contributions are: formal models, prototype implementation, extensive evaluation experiments and comparison of our classifier with other alternatives like decision trees, support vector machines, neural networks etc.

*Keywords:* Fuzzy, Inductive Logic Programming, Information Extraction, Natural Language Processing, Machine Learning

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## 1. Introduction

Big amount of information on the web increases the need of automated processing. Especially machine processing and machine understanding of textual information is very difficult. Crisp methods have their limitations. In this paper we present a fuzzy system, which provides a fuzzy classification of textual web reports.

Our motivating examples are messages of accident reports on the web (Fig. 1). We would like to have a tool, which is able to classify such message by a degree of being it a serious accident.

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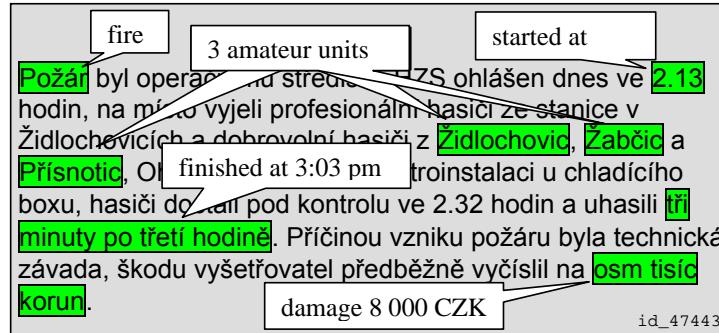


Figure 1: Example of analyzed web report.

Our solution is based on information extraction (see the emphasized pieces of information that could be extracted from a report in the Fig. 1) and on a machine learning procedure that provides rules for fuzzy classification of the reports. Our experiments deal with texts in the Czech language but our method is general and can be used with any structured linguistic representation. In this paper we do not provide many details about the information extraction part of the solution. We concentrate on the classification part.

The main contributions of this paper can be stated as follows:

- formal models for fuzzy classification of information from web reports
- prototype implementation and
- experimental evaluation of our fuzzy classification system.

Our paper is organized as follows: In the section 2 we introduce some works that are closely related to ours. In section 3 we develop our models and methods and the design of our system, focusing on the description of linguistic analyzers, inductive logic programming (ILP), fuzzy inductive logic programming (fILP) and several translations of a fuzzy ILP task to crisp ILP. In the section 4 we describe the system prototype implementation, the data and our evaluation experiment. In the section 5 we present the results of the experiment and compare our methods with other classifiers, which are well-known in machine learning. The section 6 concludes the paper.

## 2. Related Work

There are plenty of systems dealing with text mining and text classification. In (Reformat et al., 2008) the authors use ontology modeling to enhance

text identification. The authors of (Chong et al., 2005) use preprocessed data from National Automotive Sampling System and test various soft computing methods to modeling severity of injuries (some hybrid methods showed best performance). Methods of Information Retrieval (IR) are very numerous, with extraction mainly based on key word search and similarities. The Connection of IR and text mining techniques with web information retrieval can be found in Chapter Opinion mining in the book of Bing Liu (Liu, 2007).

### 3. Models, methods, design of the system

A general schema of our experimental system is shown on the Fig. 2. We use our previously developed web information extraction tools based on third party linguistic analyzers (the upper two dashed arrows, this is not a subject of this paper). We extract some structured information from the web and the extracted information is then translated to an ILP knowledge base and along with an user rating it is used for the classification. (We assume that a small amount of learning data is annotated by a human user.) The classification is based on ILP and it could be *fuzzy* or *crisp* (see in next sections).

#### 3.1. Linguistic Analysis

In this section we will briefly describe the linguistic tools that we have used to produce linguistic annotations of texts. These tools are being developed in the Institute of Formal and Applied Linguistics in Prague, Czech Republic. They are publicly available – they have been published on a CDROM under the title PDT 2.0 (Hajič et al. (2006) – first five tools) and in (Klimeš (2006) – Tectogrammatical analysis). These tools are used as a processing chain. At the end of the chain they produce tec-

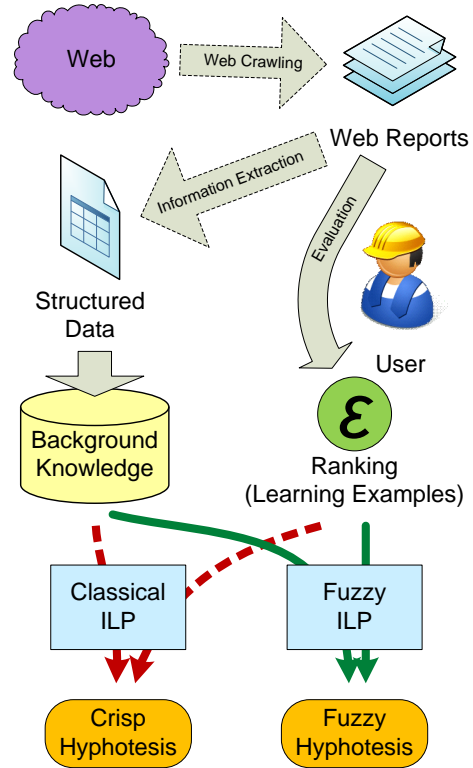


Figure 2: Schema of our system.

togrammatical (Mikulová et al., 2006) dependency trees built up from the text.

**Tool 1.** Segmentation and tokenization consists of tokenization (dividing the input text into words and punctuation) and segmentation (dividing a sequences of tokens into sentences).

**Tool 2.** Morphological analysis assigns all possible lemmas and morphological tags to particular word forms (word occurrences) in the text.

**Tool 3.** Morphological tagging consists in selecting a single pair lemma-tag from all possible alternatives assigned by the morphological analyzer.

**Tool 4.** Collins’ parser – Czech adaptation. Unlike the usual approaches to the description of English syntax, the Czech syntactic descriptions are dependency-based, which means, that every edge of a syntactic tree captures the relation of dependency between a governor and its dependent node. Collins’ parser gives the most probable parse of a given input sentence.

**Tool 5.** Analytical function assignment assigns a description (analytical function – in linguistic sense) to every edge in the syntactic (dependency) tree.

**Tool 6.** Tectogrammatical analysis produces linguistic annotation at the tectogrammatical level, sometimes called “layer of deep syntax”. An example of a tectogrammatical tree can be seen on the Fig. 3. Annotation of a sentence at this layer is closer to the meaning of the sentence than its syntactic annotation and thus information captured at the tectogrammatical layer is crucial for machine understanding of natural language (Klimeš, 2006).

### *3.2. Web Information Extraction*

After the content of a web resource is analyzed by the above mentioned linguistic tools, the output linguistic data is stored in the form of tectogrammatical trees. To achieve our objectives we have to extract information from this representation. Here we refer to our previous work (Dědek and Vojtáš, 2008a,b; Dědek et al., 2008). A long path of tools starting with web crawling and resulting with the extracted structured information has been developed in our previous works. In the Fig. 3 nodes of the tectogrammatical tree

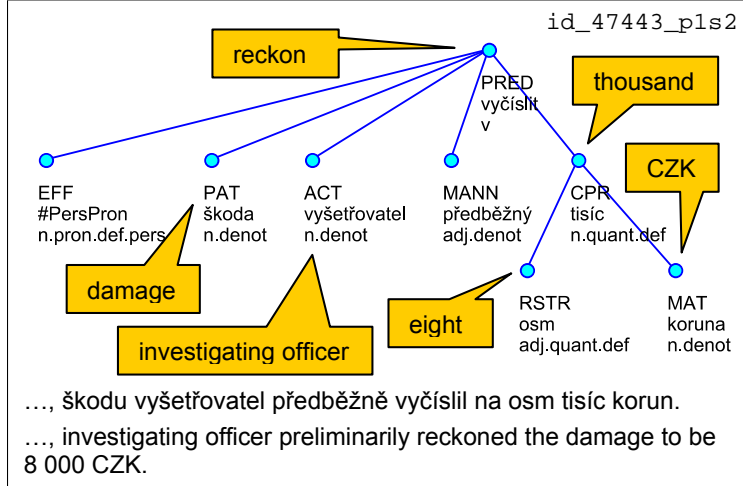


Figure 3: Example of a linguistic tree of one of analyzed sentences.

are decorated. A piece of information about the damage of 8000 CZK can be found there (the three nodes on the right). We have used ILP to learn rules, which are able to detect these nodes. The extraction process requires a human assistance when annotating the training data.

Note that our method is general and is not limited to Czech and can be used with any structured linguistic representation.

### 3.3. Classical ILP

In our application we are facing the challenge of induction and/or mining on several places. First we need an inductive procedure when extracting attributes of an accident from web reports texts.

Second (the subject of this paper) we need an inductive procedure when trying to explain the degree of seriousness of an accident by the attributes of this accident (the attributes form our background knowledge and we will often refer to them as a background knowledge). The places where induction has to be used have following requirements:

- the data and the classification is/can be fuzzy,
- in the case of tectogrammatical trees the background knowledge is multi-relational.

These requirements and our previous experience with fILP led us to chose the fILP as the machine learning inductive technique in our system. To make the paper readable we present a short description of the ILP techniques bellow.

A set of examples  $E = P \cup N$  is given, where  $P$  contains positive and  $N$  negative examples, and a background knowledge  $B$ . The task of ILP is to find a hypothesis  $H$  such that

$$(\forall e \in P)(B \cup H \models e)$$

and

$$(\forall e \in N)(B \cup H \not\models e).$$

Typically,  $E$  consists of ground instances of the target predicate, which is to be classified - in our case accidents.  $B$  typically consists of several predicates (relational tables), which describe properties of an object, which is to be classified – in our case properties of an accident. The background knowledge can contain also some rules. A hypothesis  $H$  typically consists of logic programming rules.  $H$  added to  $B$  entails all positive examples and no negative examples. Main advantage of ILP is its multirelational character, namely  $B$  can reside in several relational tables.

#### 3.4. Fuzzy and GAP induction

In our presentation of ILP we follow Dzeroski and Lavrac (2001) and Muggleton and de Raedt (1994), for fILP we follow the paper of T. Horváth and P. Vojtáš (Horváth and Vojtáš, 2007) about fuzzy inductive logic programming.

We use the approach of the fuzzy logic in narrow sense developed by J. Pavelka (Pavelka, 1979) and P. Hájek (Hájek, 1998). Formulas are of the form  $\varphi, x$  ( $\varphi$  is syntactically the same as in the crisp case), they are graded by a truth value  $x \in [0, 1]$ . A structure  $\mathcal{M}$  consist of a domain  $M$  and relations are interpreted fuzzy (we do not consider function symbols here). The evaluation  $\|\varphi\|_{\mathcal{M}}$  of a formula  $\varphi$  uses truth functions of many valued connectives (our logic is extensional and/or truth functional). The satisfaction  $\models_f$  is defined by

$$\mathcal{M} \models_f (\varphi, x) \text{ iff } \|\varphi\|_{\mathcal{M}} \geq x.$$

A fuzzy set of examples  $\mathcal{E} : E \longrightarrow [0, 1]$  and a fuzzy background knowledge  $\mathcal{B} : B \longrightarrow [0, 1]$  are given. The task of fILP is to find a fuzzy hypothesis  $\mathcal{H} : H \longrightarrow [0, 1]$  such that

$$(\forall e_1, e_2 \in E)(\forall \mathcal{M})(\mathcal{M} \models_f \mathcal{B} \cup \mathcal{H})$$

we have

$$\mathcal{E}(e_1) > \mathcal{E}(e_2) \Rightarrow \|e_1\|_{\mathcal{M}} \geq \|e_2\|_{\mathcal{M}}.$$

That is, it cannot happen that

$$\mathcal{E}(e_1) > \mathcal{E}(e_2) \wedge \|e_1\|_{\mathcal{M}} < \|e_2\|_{\mathcal{M}},$$

or rephrased: if  $\mathcal{E}$  is rating  $e_1$  higher than  $e_2$ , then it cannot happen that  $e_1$  is rated worse than  $e_2$  in a model of  $\mathcal{B} \cup \mathcal{H}$ .

Typically,  $\mathcal{E}$  consists of ground instances of the target predicate, which are classified in truth degrees – in our case a degree of seriousness of an accident.  $\mathcal{B}$  typically consists of several fuzzy predicates (fuzzy relational tables), which describe properties of an object, which is to be classified – in our case fuzzy properties of an accident – a degree of injury, a degree of damage, etc. A hypothesis  $\mathcal{H}$  typically consists of a fuzzy logic program, which, when added to  $\mathcal{B}$ , prevents of misclassification (better can not be declared to be worse, nevertheless can be declared as having the same degree — for more detailed discussion on this definition of FILP we refer to the paper (Horváth and Vojtáš, 2007)). Moreover, in practice, we use GAP – Generalized Annotated Programs, so graded formulas will be sometimes understood as annotated (with crisp connectives and with a more complex annotation of the heads of rules). This is possible, because in (Krajci et al., 2004) we have shown that (some extension of) fuzzy logic programming is equivalent to (some restriction of) generalized annotated programs.

### 3.5. Translation of fuzzy ILP task to several crisp ILP tasks

As far as there is no implementation of FILP or GAP, we have to use a classical ILP system. Fortunately any FILP task can be translated to several crisp ILP tasks (subject to some rounding and using a finite set of truth values).

Assume that our fuzzy sets take values from a finite set of truth values  $T : \{0, 1\} \subseteq T \subseteq [0, 1]$ . For each predicate  $p(x)$  in  $B$  we add an additional attribute  $p(x, t)$  to express the truth value. We construct two crisp background knowledge sets  $\mathcal{B}_T^{raw}$  and  $\mathcal{B}_T^{mon}$  as follows:

- The first ( $\mathcal{B}_T^{raw}$ ) is a direct coding of a fuzzy value by an additional attribute:  
If  $\mathcal{B}(p(x)) = t$ ,  $t \in T$ , then we add  $p(x, t)$  to  $\mathcal{B}_T^{raw}$ .

- The second ( $\mathcal{B}_T^{mon}$ ) is obtained by a process called monotonization:  
If  $\mathcal{B}(p(x)) = t$ ,  $t \in T$ , then for all  $t' \in T$ ,  $t' \leq t$  we add  $p(x, t')$  to  $B_T^{mon}$ .

Also example sets are constructed in two ways.

- For all  $t \in T$  we create a crisp example set  $E_t = P_t \cup N_t$ , where

$$e \in P_t \text{ iff } \mathcal{E}(e) = t$$

and  $N_t$  is the rest of  $E$ .

- For all  $t \in T$  we create a crisp example set  $E_{\geq t} = P_{\geq t} \cup N_{< t}$ , where

$$e \in P_{\geq t} \text{ iff } \mathcal{E}(e) \geq t$$

and  $N_t$  is the rest of  $E$ .

These two translation create two ILP tasks, the first one (*raw*) is purely crisp and the second one (*mon*) can be understood as (and translated back to) fILP.

- The *raw ILP task* is given by  $B_T^{raw}$  and  $E_t$  for each  $t \in T$ . As a result it produces a set of hypotheses  $H_t$ .
- The *mon ILP task* is given by  $B_T^{mon}$  and  $E_{\geq t}$  for each  $t \in T$ . As a result it produces a set of hypotheses  $H_{\geq t}$  guaranteeing examples of degree of at least  $t$ .

Note that variable bindings in  $B$  have no bindings on the truth value attribute, which was added to each predicate, and hence there are no variable bindings on the truth value attribute in  $H_{\geq t}$ . We did not add an additional truth value attribute to the predicates in  $E$

Now we sketch the translation of the *mon ILP task* to GAP (fILP) rules. Let us assume that  $C$  is the target predicate in the domain of  $\mathcal{E}$ . We define  $\mathcal{H}$  with a domain consisting of one GAP rule

$$C(y) : u(x_1, \dots, x_m) \leftarrow B_1 : x_1 \& \dots \& B_n : x_m,$$

here  $B_1 : x_1 \& \dots \& B_n : x_m$  is the enumeration of all predicates in  $B$ .

Assume that  $B_1(y_1, t_1), \dots, B_n(y_n, t_n)$  are some of the predicates in  $B$  (for simplicity enumerated from 1 to  $n$ ,  $n \leq m$ ). Then for each rule

$$R = C(y) \Leftarrow B_1(y_1, t_1), \dots, B_n(y_n, t_n)$$



in  $H_t$  we give a constraint in definition of  $u$  as follows

$$U_R = u(x_1, \dots, x_m) \geq t \text{ if } x_1 \geq t_1, \dots, x_n \geq t_n.$$

Note that  $x_{n+1}, \dots, x_m$  have no restrictions.

We claim, that if all  $H_t$  were correctly learned by an crisp ILP system then for the minimal solution  $u$  of all constraints  $U_R$  the rule

$$C(y) : u(x_1, \dots, x_m) \leftarrow B_1 : x_1 \& \dots \& B_n : x_n$$

is a correct solution of the fILP task given by  $\mathcal{E}$  and  $\mathcal{B}$ , for all  $R \in H_t$  and  $t \in T$ . Our presentation is here a little bit simplified and we freely switch between fuzzy and GAP programs, which are known to be equivalent, see in (Krajci et al., 2004).

#### 4. The system prototype and our experiment

The main experiment presented in this paper leads to the seriousness classification of an accident presented on a web report, which is one of possible utilizations of the extracted information. We use web reports of fire departments of several regions of the Czech Republic. These reports are written Czech and can be accessed through the web of the General Directorate of the Fire and Rescue Service of the Czech Republic<sup>1</sup>.

For our experiment we have selected a collection of 50 web reports. We have identified several features presented in these reports and manually extracted corresponding values. This will be described in more detail in the section 4.2. To each report we have also assigned a value of overall ranking of seriousness of the presented accident, which is the target of the classification. The whole dataset can be downloaded from our Fuzzy ILP classifier's web page<sup>2</sup>.

In this experiment we have not used an information extracted by our automated information extraction tools. In this paper we are concentrated on the classification and the actual source of the information is not so important. The integration step is still waiting to be done.

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<sup>1</sup><http://www.hzscr.cz>

<sup>2</sup><http://www.ksi.mff.cuni.cz/~dedek/fuzzyILP/>

attribute name	distinct values	missing values	monotonic
size (of file)	49	0	yes
type (of accident)	3	0	no
damage	18	30	yes
dur_minutes	30	17	yes
fatalities	4	0	yes
injuries	5	0	yes
cars	5	0	yes
amateur_units	7	1	yes
profesional_units	6	1	yes
pipes	7	8	yes
lather	3	2	yes
aqualung	3	3	yes
fan	3	2	yes
ranking	14	0	yes

Table 1: Accident attributes.

#### 4.1. Experiment description

For the seriousness classification we have used two inductive logic approaches – Crisp ILP and Fuzzy ILP (as described above). Technically the difference between the approaches consists in different setting of the *ILP task*. Both can be done with a classical ILP tool. We have used “*A Learning Engine for Proposing Hypotheses*” (Aleph v5<sup>3</sup>), which we consider very practical. It uses quite effective method of *inverse entailment* (Muggleton, 1995) and keeps all handy features of a Prolog system (it is supported by YAP and SWI Prolog) in its background.

We have compared results of the Crisp and Fuzzy ILP approaches with other classification methods and in our experiment the fuzzy approach made better results than the crisp one and also than many other methods. See the section 5 for the details.

#### 4.2. Features of accidents

The table 1 summarizes all features (or attributes) that we have obtained from accident reports. Except the attribute `type` (type of an accident – `fire`, `car_accident` and `other`) all the attributes are numerical and so monotonizable. There are cases when the value of an attribute is unknown.

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<sup>3</sup><http://www.comlab.ox.ac.uk/activities/machinelearning/Aleph/>

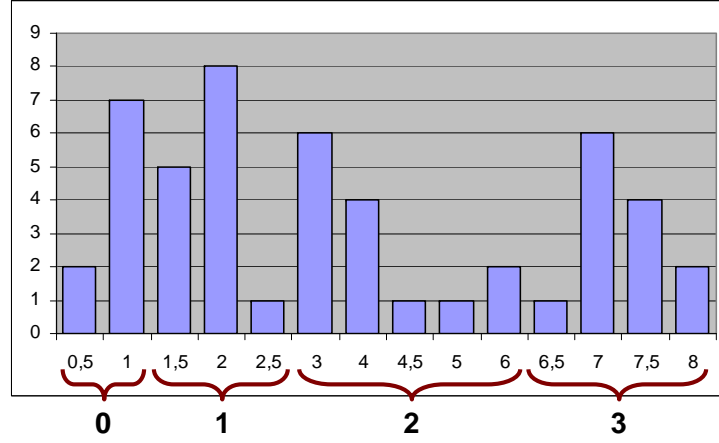


Figure 4: Frequencies of the seriousness ranking.

We have decided to make evidence of this and keep the values **unknown** in our knowledge base. A brief explanation of each attribute follows.

- **size** is the file size of the text of the particular report.
- **damage** is the amount (in CZK – Czech Crowns) of the summarized damage arisen during the reported accident.
- **dur\_minutes** is the time taken to handle the accident.
- **fatalities** and **injuries** are the numbers of fatalities and injuries taken by the accident.
- **cars** is the number of cars damaged during the accident (important during car accidents).
- **professional\_units** and **amateur\_units** are the numbers of the fireman units sent for the accident.
- **pipes** is the number of used fire pipes.
- **lather**, **aqualung** and **fan** (ventilator) indicates whether these devices were used.

#### 4.3. Seriousness ranking

Values of the overall seriousness ranking attribute were stated from “a general impression” from texts of the reports texts with respect to particular attributes. The values have evolved to 14 distinct values in the range from 0.5 to 8. A histogram with frequencies of all the values is on the Figure 4. We have divided the values into four approximately equipotent groups (see in the Fig. 4) and these groups determine the target class attribute in our classification task.

##### Crisp learning examples

```
serious_2(id_47443). %positive
```

```
serious_0(id_47443). %negative
serious_1(id_47443). %negative
serious_3(id_47443). %negative
```

##### Monotonized learning examples

```
serious_atl_0(id_47443). %positive
serious_atl_1(id_47443). %positive
serious_atl_2(id_47443). %positive
```

```
serious_atl_3(id_47443). %negative
```

Figure 5: Learning examples.

```
size(id_47443, 427).
type(id_47443, fire).
damage(id_47443, 8000).
dur_minutes(id_47443, 50).
fatalities(id_47443, 0).
injuries(id_47443, 0).
cars(id_47443, 0).
amateur_units(id_47443, 3).
profesional_units(id_47443, 1).
pipes(id_47443, unknown).
lather(id_47443, 0).
aqualung(id_47443, 0).
fan(id_47443, 0).
```

Figure 6:  $B_T^{raw}$  – crisp attributes.

```
damage_atl(ID,N) :- %unknown values
    damage(ID,N), not(integer(N)).
damage_atl(ID,N) :- %numeric values
    damage(ID,N2), integer(N2),
    damage(N), integer(N), N2>=N.
```

Figure 7: Monotonization of attributes ( $\text{damage\_atl} \leftarrow \text{damage}$ ).

#### 4.4. Data transformation

To use ILP for the classification task we have to translate the input data to the Prolog-like logic representation. As already described in previous sections, the transformations in the crisp and in the fuzzy case are different. Here we will describe the implementation details of the construction of the crisp and fuzzy knowledge bases and example sets.

For the construction of the crisp example set  $E_t$  we encode the target (class) predicate as **serious\_t**. The letter **t** stands for the actual seriousness degree. We use multiple unary predicates **serious\_0**, **serious\_1**, etc.,

```

serious_0(ID) :- serious_atl_0(ID),
                  not(serious_atl_1(ID)),
                  not(serious_atl_2(ID)),
                  not(serious_atl_3(ID)).

serious_1(ID) :- serious_atl_1(ID),
                  not(serious_atl_2(ID)),
                  not(serious_atl_3(ID)).

serious_2(ID) :- serious_atl_2(ID),
                  not(serious_atl_3(ID)).

serious_3(ID) :- serious_atl_3(ID).

```

Figure 8: Conversion rules for monotized hypotheses (`serious_t`  $\leftarrow$  `serious_atl_t`).

instead of one binary predicate `serious(ID,Degree)`. These two cases are equivalent and we have decided to use the unary one because it is better for visual distinction of the multiple ILP tasks.

For the construction of the fuzzy (or monotized) example set  $E_{\geq t}$  we encode the target predicate as `serious_atl_t`, see in the Fig. 5.

For the construction of the crisp background knowledge  $B_T^{raw}$  we use a simple translation of the data to the predicates. It is illustrated on the Fig. 6).

For the construction of the monotized background knowledge  $B_T^{mon}$  we reuse the crisp background knowledge and add monotization rules. An example of the monotization rules for a crisp predicate of `damage` is shown on the Fig. 7. The first rule deals with `unknown` values and the second serves for the translation.

All the negations we use (Fig. 7 and Fig. 8) are the standard Prolog *negations as failure*.

Once we have the learning examples and the background knowledge, we can run the ILP inductive learning procedure and obtain learned rules (a learned hypothesis). According to the kind of the ILP task (crisp or monotized) we obtain corresponding kind (crisp or monotized) of rules (see e.g. in the Fig. 9). But these rules cannot be used directly to solve the classification task. There are common cases when more then one rule is applicable to a single instance, which is to be classified. So we have to select which one to use. For the monotized hypothesis we select the maximum from all the possibilities. It is illustrated on the Fig. 8. For the crisp hypothesis there is not such clear criterion, so we simply use the fist applicable rule.

On the other hand in the crisp case there are often many instances, which cannot be classified because there is no applicable rule. (In our experiment

```

serious_0(A):-dur_minutes(A,8).
serious_0(A):-type(A,fire),pipes(A,0).
serious_0(A):-fatalities(A,0),pipes(A,1),lather(A,0).
serious_1(A):-amateur_units(A,1).
serious_1(A):-amateur_units(A,0),pipes(A,2),aqualung(A,1).
serious_1(A):-damage(A,300000).
serious_1(A):-damage(A,unknown),type(A,fire),prof_units(A,1).
serious_1(A):-dur_minutes(A,unknown),fatalities(A,0),cars(A,1).
serious_2(A):-lather(A,unknown).
serious_2(A):-lather(A,0),aqualung(A,1),fan(A,0).
serious_2(A):-amateur_units(A,2),prof_units(A,2).
serious_2(A):-dur_minutes(A,unknown),injuries(A,2).
serious_3(A):-fatalities(A,1).
serious_3(A):-fatalities(A,2).
serious_3(A):-injuries(A,2),cars(A,2).
serious_3(A):-pipes(A,4).

serious_atl_0(A).
serious_atl_1(A):-injuries_atl(A,1).
serious_atl_1(A):-lather_atl(A,1).
serious_atl_1(A):-pipes_atl(A,3).
serious_atl_1(A):-dur_minutes_atl(A,unknown).
serious_atl_1(A):-size_atl(A,764),pipes_atl(A,1).
serious_atl_1(A):-damage_atl(A,8000),amateur_units_atl(A,3).
serious_atl_1(A):-type(A,car_accident).
serious_atl_1(A):-pipes_atl(A,unknown),randomized_order_atl(A,35).
serious_atl_2(A):-pipes_atl(A,3),aqualung_atl(A,1).
serious_atl_2(A):-type(A,car_accident),cars_atl(A,2),prof_units_atl(A,2).
serious_atl_2(A):-injuries_atl(A,1),prof_units_atl(A,3),fan_atl(A,0).
serious_atl_2(A):-type(A,other),aqualung_atl(A,1).
serious_atl_2(A):-dur_minutes_atl(A,59),pipes_atl(A,3).
serious_atl_2(A):-injuries_atl(A,2),cars_atl(A,2).
serious_atl_2(A):-fatalities_atl(A,1).
serious_atl_3(A):-fatalities_atl(A,1).
serious_atl_3(A):-dur_minutes_atl(A,unknown),pipes_atl(A,3).

```

Figure 9: Crisp and monotonized hypotheses.

there was about 51% of unclassified instances, see in the next section.) It could be caused by the lack of training data, but the monotonized case does not suffer from this shortage. We can always select the bottom class and – what is probably more important – the set of positive training examples is extended by monotonization.

## 5. Results

The Fig. 9 summarizes obtained hypotheses learned from our data:

- a crisp hypothesis learned from  $E_t$  and  $B_T^{raw}$  and
- a monotonized hypothesis learned from  $E_{\geq t}$  and  $B_T^{mon}$ .

In both cases the learning examples and the background knowledge have the origin in the same data (the same accidents). They differ in the form of the ILP task (crisp and monotonized). The crisp hypothesis uses only the crisp predicates, the monotonized hypothesis uses only the monotonized predicates.

### 5.1. Evaluation

We have evaluated both ILP methods and compared them with other machine learning procedures used in data mining. To make the comparison clear and easy to perform, we have implemented an interface between the ILP methods and the Weka data mining software<sup>4</sup> (Hall et al., 2009). This interface makes it possible to use the ILP methods as an ordinary Weka classifier for any<sup>5</sup> classification task inside the Weka software. Our implementation is publicly available. The data, source codes and an platform independent installer of the Crisp and Fuzzy ILP classifiers for Weka can be downloaded from our Fuzzy ILP classifier’s web page<sup>6</sup>. This makes our experiment repeatable according to the SIGMOD Experimental Repeatability Requirements (Manolescu et al., 2008).

For our experiment we used the Weka Experimenter and performed an experiment in which the Crisp and Fuzzy ILP classifiers were compared with five additional classifiers:

- Multilayer Perceptron (Bishop, 1996),
- Support Vector Machine classifier SMO (Keerthi et al., 2001),
- J48 decision tree (Quinlan, 1993),
- JRip rules (Cohen, 1995) and
- Additive logistic regression LogitBoost (Friedman et al., 2000).

We have evaluated all the methods two times by 10-fold cross validation on our data. The obtained results (average values) are described by the graph on the Fig. 10 and in the Table 2 (with standard deviations and decorated statistically significant values).

There is no clear winner in our experiment. But the Fuzzy ILP classifier proved better results than majority of the methods on our data and the results are statistically significant in many cases. Very good results obtained also the LogitBoost.

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<sup>4</sup><http://www.cs.waikato.ac.nz/ml/weka/>

<sup>5</sup>For the fuzzy ILP method, there is a requirement on the target (class) attribute: it has to be monotonizable (e.g. numeric).

<sup>6</sup><http://www.ksi.mff.cuni.cz/~dedek/fuzzyILP/>

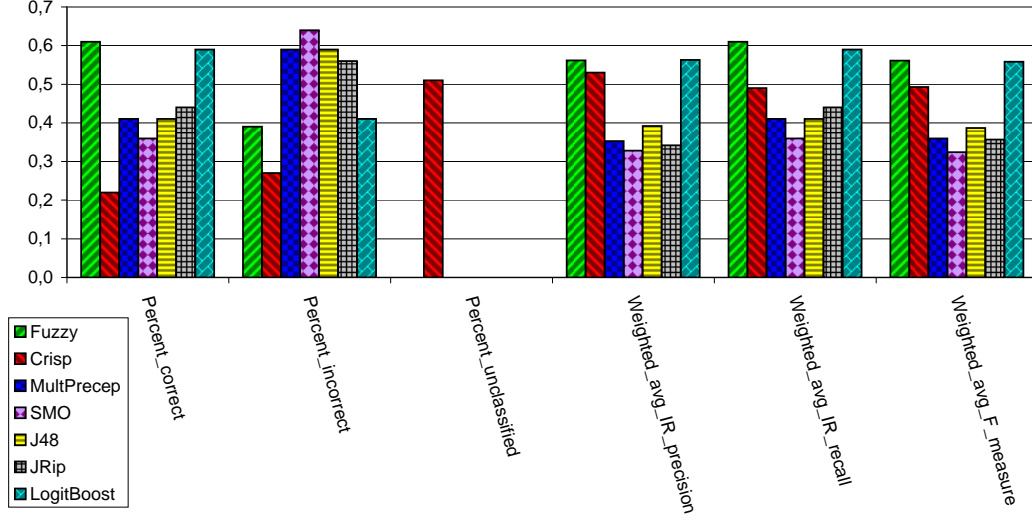


Figure 10: Evaluation of the methods – average values.

	Fuzzy	Crisp	MultPerc	SMO	J48	JRip	LBoost
Corr	0.61±.19	.22±.17●	.41±.19●	.36±.24●	.41±.22●	.44±.17●	.59±.26
Incor	.39±.19	.27±.24	.59±.19○	.64±.24○	.59±.22○	.56±.17○	.41±.26
Uncl	.00±.00	.51±.29○	.00±.00	.00±.00	.00±.00	.00±.00	.00±.00
Prec	.56±.24	.53±.37	.35±.20●	.33±.26	.39±.22	.34±.21●	.56±.28
Rec	.61±.19	.49±.32	.41±.19●	.36±.24●	.41±.22●	.44±.17●	.59±.26
F	.56±.20	.49±.33	.36±.19●	.32±.24●	.39±.21	.36±.19●	.56±.27

○, ● statistically significant improvement or degradation

Legend:

```

Fuzzy ..... czsem.ILP.FuzzyILPClassifier "
Crisp ..... czsem.ILP.CrispILPClassifier "
MultPerc .... functions.MultilayerPerceptron '-L 0.3 -M 0.2 -N 500 -V 0 -S 0 -E 20 -H a'
SMO ..... functions.SMO '-C 1.0 -L 0.0010 -P 1.0E-12 -N 0 -V -1 -W 1 -K
          \"functions.supportVector.PolyKernel -C 250007 -E 1.0\"
J48 ..... trees.J48 '-C 0.25 -M 2'
JRip ..... rules.JRip '-F 3 -N 2.0 -O 2 -S 1'
LBoost ..... meta.LogitBoost '-P 100 -F 0 -R 1 -L -1.7976931348623157E308 -H 0.1 -S 1 -I 10
          -W trees.DecisionStump'

Corr ..... Percent correct
Inor ..... Percent incorrect
Uncl ..... Percent unclassified
Prec ..... Weighted avg IR precision
Rec ..... Weighted avg IR recall
F ..... Weighted avg F measure

```

Table 2: Evaluation of the methods in 2 times 10-fold cross validation.



The LogitBoost algorithm is described in the publication of Friedman et al. (2000). The basic idea of the boosting algorithm is to learn several simple models on reweighted data and combine their opinions to get the resulting classification. In our case, the simple models were decision stamps, i.e. decision trees with only one nonleaf node. In each iteration, an optimal decision stamp for each target value is learned. Then, the training dataset is reweighted in a way that records badly classified by current model are given higher weight in the next iteration. A new record is classified as follows: for each target value, predictions of its decision stamps are summed up. The target value with the highest vote wins.

We consider boosting as an enhancement of decision trees. A deep decision tree is too dependent on the randomness in the data. It has a high variance. Boosting of (tiny) trees fits an additive logistic regression model on them, i.e. uses a statistically justifiable way of building a collection of tiny trees. This seems to have low variance and keeps high expressiveness (does not increase bias dramatically).

## 6. Conclusion

In this paper we have presented a fuzzy system, which provides a fuzzy classification of textual web reports. Our approach is based on usage of third party linguistic analyzers, our previous work on web information extraction and fuzzy inductive logic programming.

Main contributions are formal models, prototype implementation of the presented methods and an evaluation experiment. Our data and our implementation is publicly available on the Web. The experiment has shown the performance of the presented methods and compared them with other machine learning procedures used in data mining. The Fuzzy ILP classifier proved better results than majority of the methods on our data. The results are statistically significant in many cases. We see the advantage of the Fuzzy ILP classifier in the fact that monotonization leads to the extension of the learning domain and it utilizes the fact that the domain is or can be monotonically ordered.

We have not performed any additional experiments with other data sets so far because we are primarily interested in our data. This is to be done in the future works and thanks to the public implementation it could be done by anyone interested.

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