An Intelligent System Dealing with Complex Nuanced Information within a Statistical Context

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Abstract. The main object of this paper is to propose an intelligent system dealing with affirmative or negative information. We do not refer to a logical negation but to a linguistic one. Moreover, not only atomic but also complex nuances can be denied. Among the intended meanings of a linguistic negation, the choice is made by using the strength of the user negation and a preference principle which takes into account the answer simplicity.

1 Introduction

In this paper, we present a general model dealing with nuanced information expressed in affirmative or negative forms as they may appear in knowledge bases including, rules like "If the patient is not vaccinated, the inflammation due to the test is not moderate or high" and facts like, "the inflammation due to the test is not small". In our work, we do not refer to classical logic negation but to a new kind of negation called *linguistic negation*. The representation of *affirmative information* can be made by using the model proposed in [1] which can deal with nuanced information within a fuzzy context [11], and the representation of *negative information* can be based on the methodology proposed in [6–8]. Previous models [6], [8] have been improved in [7] in such a way that a user can now deny a combination of nuanced properties called here a *complex nuance*. The *first object of this paper* has been to improve previous negation operators in such a way that all *negation forms* F_t of complex nuances U come from the mechanism, denoted *"All ... except ...",* which defines Neg_t(x, U), the *reference frame* of the linguistic negation of "x is U", given F_t. The strength ρ with which the user denies "x is U" defines Neg_t^ρ (x, U) a set containing V the affirmative translations of the denied nuance U. In many cases, the user wishes only one affirmative translation, so a choice strategy extracts one intended meaning belonging to Neg_t^ρ (x, U). In [6, 7], the choice is made among the solution leading to the greatest membership degree μ_V(x). When the linguistic negation is restricted to one nuanced property, statistical data have been exploited to make this uncertain choice [3]. *The second object of this paper* has been to enrich this choice strategy in order to deal with denied *complex nuances*. This is made by taking into account *statistical data* on the discourse universe, such as the *frequency of use* of a *fuzzy property* associated with a concept, and of a *nuance* applied to a property. We also suggest taking into account *linguistic statistics* about the use of negation in natural language. In order to illustrate this model, we consider an example of *reasoning on medical facts and rules in a medical diagnosis field.* The statistical information are calculated by exploiting index cards written by a doctor after his consultations. From the following three index cards (**ICi**) and five rules (**Rj**), we wish to deduce a diagnosis.

IC1: The temperature is not very low, the eardrum color is really very red, fat eating is low, the tension is perfectly (i.e. "exactly") normal

IC2: The temperature is not very high, the eardrum color is normal, fat eating is high, and the tension is normal.

IC 3: The temperature is rather little high, the eardrum color is normal, fat eating is very low or really moderate, the tension is normal, and the inflammation due to the monotest is not small.

R1: If the temperature is high and the eardrum color is very red, the disease is an otitis.

R2: If the temperature is not normal, the patient is ill.

R3: If fat eating is not moderate, the cholesterol risk is not low.

R4: If the cholesterol risk is high, a diet with no fat is recommended.

R5: If the patient is not vaccinated, the inflammation due to the test is not moderate or high.

2 Nuanced Expression Probability

We suppose that the discourse universe is characterized by a finite number of *concepts* C_i. A set of *basic properties* P_{ik} is associated with each C_i, whose *description domain* is denoted as D_i. For example, the concept "temperature" can be characterised by the basic properties "low", "normal" and "high" ; the concept "eardrum colour" by the basic properties "normal" and "red" ; the concept "cholesterol risk" by the properties "not-existent", "low", "moderate", "high" and "tremendous", the concept "feat eating" by the properties "zero", "low", "moderate" and "high", and the concept "inflammation" by the properties "not-existent", "small", "moderate" and "high". Moreover, *linguistic modifiers* allow us to express *nuanced knowledge* like "the temperature is *rather* normal". In this paper, we use the methodology proposed in [1] to cope with affirmative information like "x is $f_\alpha m_\beta P_{ik}$" and with negative information like "x is not $f_\alpha m_\beta P_{ik}$" (where f_α and m_β are *linguistic modifiers*). In the following, $f_\alpha m_\beta$ is called the *nuance* applied to P_{ik}. The modifiers f_α and m_β are taken from two ordered sets of *fuzzy modifiers*. The first one groups *translation modifiers* which operate both a translation and a precision variation on the basic property: in this paper, we use $M_9=\{m_\beta\}_{\beta\in[1..9]}$ = {*extremely little, very very little, very little, rather little, moderately, rather, very, very very, extremely*} (Figure 2). The second set contains *precision modifiers* which make it possible to modify the precision of the properties. Here, we use $F_6= \{f_\alpha\}_{\alpha\in[1..6]}$ = {*vaguely, neighboring, more or less, moderately, really, exactly*} (Figure 2). These two sets are totally ordered by the relation: $m_\alpha < m_\beta$ (resp. $f_\alpha < f_\beta$) $\Leftrightarrow$ $\alpha < \beta$. The modifier "*moderately*" is equivalent to the empty word.

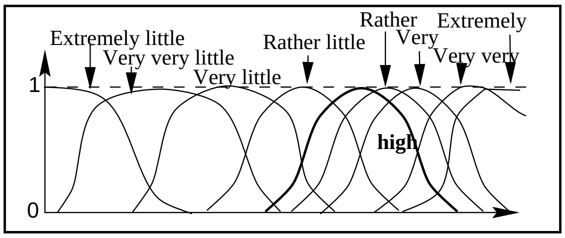

Fig. 1. Translation Modifiers

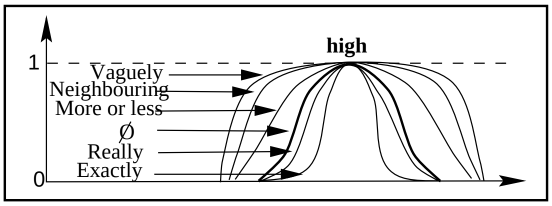

Fig. 2. Precision Modifiers

From the set of index cards owned by the doctor, we can extract statistical knowledge about the use of nuance expressions in his language. Note that these statistics are computed only on *affirmative* expressions contained on these index cards. After index cards analysis, *the percentages of use of every basic property*, when the doctor speaks about a given concept, are available.

Example: *For the concept of temperature, the statistical probability that he uses the term "low" is calculated by counting the occurrences of the term "low" (possibly with a nuance) with regard to the total number of expressions concerning temperature. For instance: 5% of positive expressions concerning "temperature" use the term "low", 80% the term "normal" and 15% the term "high".*

In the same way, we can obtain statistics about the use of every possible nuance for every basic property. In practice, we only need statistics about the use of *relevant* nuances: a combination of modifiers $f_\alpha m_\beta$ is *relevant* if it is used in English. Out of 54 possible nuances, finally only 20 are relevant. The statistics concerning the use of these 20 relevant combinations are computed in the same way as for basic properties.

Example: *For the property "low" associated with the concept of "temperature", the statistical probability that the doctor uses the nuance "really very" is computed by counting the occurrences of "really very low" with regard to the total number of expressions containing "low" and concerning temperature. For instance: 5% of positive expressions containing "low" use the nuance "really very", 20% the empty nuance, 1% "very little", 8% "very"...*

Proposition 1. *For any expression $e =$ "x is $f_\alpha m_\beta$ P_{ik}", the statistical probability that the doctor uses this expression in an index card when he speaks about the concept C_i is: if $Pr(bp(e) = P_{ik}) > 0$ then $Pr(e) = Pr(bp(e) = P_{ik}) \times Pr(n(e) = f_\alpha m_\beta | bp(e) = P_{ik})$ else we set $Pr(e) = 0$, where $n(e)$ and $bp(e)$ are respectively the nuance and the basic property of e.*

Example: *The statistical probability that "very low" appears in affirmative expressions concerning a patient "temperature" is equal to* $0.05 \times 0.08 = 0.004$.

Definition 1. *Given $G = \{A_h\}_{h=1,\ldots p}$ a subset of N_i (the set of all nuanced properties associated with the concept C_i) any finite combination of nuanced properties of G based upon the operators $\wedge$ and $\vee$, denoted as $U(A_1, .., A_h, .., A_p)$, is said to be a* **complex nuance induced from G**. *The* **set of all complex nuances induced from** *G is* **denoted $\mathbf{G}^*$**.
If no confusion is possible, then U stands for $U(A_1, \ldots, A_h, \ldots, A_p)$.
More formally, if we suppose that any complex nuance is defined in the **prefixed form,** *then $\mathbf{G}^*$ can be recursively defined as follows:*
1 - $\forall A_h \in G$, $A_h \in G^*$, 2 - $\forall U \in G^*$, $\forall V \in G^*$, $\gamma UV \in G^*$, with $\gamma \in \{\wedge, \vee\}$, 3 - Any element of G^* results from a finite number of uses of rules 1 and 2.

Definition 2 (First preference principle). *Let $U(A_1, .., A_p)$ and $V(B_1, .., B_q)$ be to complex nuances where every A_i (resp. B_j) are distinct: U is* preferred *to V if and only if $\prod_{j=1..p} Pr(A_j) > \prod_{j=1..q} Pr(B_j)$.*

Example: *The expression "x is low" is preferred to "x is low or really very low" since Pr("x is low") >Pr("x is low") $\times$ Pr("x is really very low"),* $0.1 > 0.1 \times 0.0025 = 0.00025$.

3 Linguistic Negation Translations

Taking into account several linguistic results [5, 4, 2], Pacholczyk showed in [6] that when the user says "*x is not U*":(1) he *rejects* the sentence "*x is U*", and (2) he *possibly refers* either to another object y (i. e., "y is U") or to another property V (i. e., "x is V") distinct from U but which concerns the same concept C_i. The linguistic negation concept used here is defined, as in [9], by a one-to-many mapping from E into $\mathfrak{P}(\mathfrak{E})$ (E parts), called here a *multi-set function.* In this paper we propose a *new definition of the concept of linguistic negation* which can be viewed as a *generalization of the one* proposed in [8]. Let M be the set of every possible modifier combinations (including irrelevant combinations) ($M = \{f_\alpha\}_{\alpha \in [1..6]} \times \{m_\beta\}_{\beta \in [1..9]}$). Given a concept C_i, let $B_i = \{P_{ik}\}_{k \in I\!N}$ be the set of basic properties associated with C_i having as definition domain D_i, N_{ik} be the set of all nuanced properties associated with property P_{ik}, and N_i be the set of all nuanced properties associated with the concept C_i. Given $G \subset N_i$, G^* denotes the set of all complex nuances induced from G. Then, for any concept C_i, we define a linguistic negation operator as a *parameterized function Neg_t*:

Definition 3. *For any concept C_i, let U and V be two complex nuances induced from N_i^*, such that: $U = U(n_1 P_{ik_1}, \ldots, n_j P_{ik_j}, \ldots, n_p P_{ik_p})$ and $V = V(m_1 P_{il_1}, \ldots, m_j P_{il_j}, \ldots, m_q P_{il_q})$. and let $L = \{k_1, \ldots, k_j, \ldots, k_p, l_1, \ldots, l_j, \ldots, l_q\}$ A* **linguistic negation operator** *is a function $Neg_t : D_i \times N_i^* \to \mathfrak{P}(\mathfrak{D}_i) \times \mathfrak{P}(\mathfrak{N}_i^*)$ defined as follows, knowing that $n \in M, \gamma \in \{\wedge, \vee\}$ and $t \in \{0, 1, 2, 3, 4, 5\}$:*
- $Neg_0(x,u) = (\emptyset, \emptyset)$; $Neg_1(x, u) = (D_i \backslash \{x\}, \{u\})$; $Neg_2(x, u) = (\{x\}, N_i^* \backslash \{u\})$
- $Neg_3(x, nP_{ik}) = (\{x\}, N_{ik}^* \backslash \{nP_{ik}\})$
and $Neg_3(x, \gamma UV) = (\{x\}, (\cup_{h \in L} N_{ih})^* \setminus \{\gamma UV\})$
- $Neg_4(x, nP_{ik}) = (\{x\}, N_i^* \setminus N_{ik}^*)$; $Neg_4(x, \gamma UV) = (\{x\}, N_i^* \setminus (\cup_{h \in L} N_{ih})^*)$
- $Neg_5(x, nP_{ik}) = (\{x\}, N_{im}^*)$ where $P_{im} \neq P_{ik}$ is a precise property in B_i
and $Neg_5(x, \gamma UV) = (\{x\}, (\cup_{m \in G} N_{im})^*)$ where G is a set of index such that $L \cap G = \emptyset$ and $\{P_{im} \in N_i \mid m \in G\} \subset B_i$.

It is possible to associate a **standard form $\mathbf{F}_t$** for "x is not U" with *each scope of the negation operator.*When a speaker says "*x is not U*", he means that:
- $\mathbf{F}_0$: *For this x, "x is U " is rejected and there is not any corresponding affirmative expression.* Saying "the disease is not an otitis" may not admit any affirmative translation, the only thing that the doctor knows about the disease is that it is not an otitis.
- $\mathbf{F}_1$: *Another object of the same domain satisfies the same nuanced property U.* "x is not U" means "not(x) is U". The doctor can note that "Mary is not ill" because he knows that "it is John and Jack who are ill".
- $\mathbf{F}_2$: *The same x satisfies another complex nuance of N_i^*.* For instance, the doctor can say that "The temperature is not very high" because he hesitates between "the temperature is normal" and "the temperature is little high".
- $\mathbf{F}_3$: *The same x satisfies another complex nuance of N_i^* induced from the same basic properties.* The doctor can say "the temperature is not low" because he thinks that "the temperature is really low".
- $\mathbf{F}_4$: *The same x satisfies a complex nuance of N_i^* which is not induced from the same basic properties.* The doctor can say "cholesterol risk is not low" because he thinks that "cholesterol risk is at least medium".
- $\mathbf{F}_5$: *The same x satisfies a complex nuance of N_i^* induced from other* ***precise*** *basic properties.* The doctor can say that "the patient is not very big" since he thinks that "he is rather thin".
- $\mathbf{F}_6$: *The same x satisfies a complex nuance induced from new affirmative basic properties.* In this case, "*x is not U*" means that the new property "not-U" is associated to the same concept as U. "The patient is not seriously ill" may introduce a new basic property "not-seriously-ill".

Note that, in this paper, we are not concerned with the forms F_1 or F_6.

Remark 1. Let $t \in \{2, .., 5\}$, "x is not U" means that there exists a complex nuance V such that we have "x is V". This V is defined as follows: $V \in F$ such that $Neg_t(x, U) = (\{x\}, F)$ *with* $F \in \mathfrak{P}(\mathfrak{N}_i^*)$. In other words, **"x is V" is an affirmative translation of "x is not U" in form F_t.**
If no confusion is possible, in the following, we simply write V$\in Neg_t(x, U)$.

Proposition 2. $Neg_5(x, u) \subset Neg_4(x, u) \subset Neg_2(x, u)$; $Neg_3(x, u) \subset Neg_2(x, u)$.

Assumption : Statistics on the most used negation forms are available for any nuanced expression. These statistics come from a linguistic analysis of English negation.

For instance, "Temperature is not normal" usually corresponds to a nuance of "low" or "normal" or "high" and refers to the form F_2 in 70% of cases. On the other hand, "Temperature is not very low" is related in 60% of cases to a nuance of "high" (F_5). "Fat eating is not moderate" usually means that it is at least "high" (F_5). "Cholesterol risk is not low" means usually that it can be "moderate", "high" or "tremendous" (F_4). "Temperature is not very high" usually corresponds to another nuance of "high" (F_3).

4 Linguistic Negation Strength

Let us notice that the subset $Neg_t(x, U)$ systematically excludes U but it must also exclude complex nuances which are close to U. So, a complex nuance V may be chosen as a negation of an expression $u =$"x is U" if V is a complex nuance associated with the same concept as U and if for a given x: if $\mu_U(x)$ (resp. $\mu_V(x)$) is close to 1 then $\mu_V(x)$ (resp. $\mu_U(x)$) is close to 0.

Definition 4. *Let $0.5 \leq \rho \leq 1$. Let us suppose that C_i is a concept, F_t a standard form ($t \in [2..5]$), Neg_t a linguistic negation operator and $U(A_1, , A_h, , A_p)$ (or U) is a* **complex nuance induced from** N_i. *The* **linguistic negation** *of U* **applied to** x, **given** ρ *and the* **standard form** F_t, *denoted as* $\mathbf{Neg}_t^\rho\mathbf{(x, U)}$, *is a set of complex nuances induced from N_i. More precisely, $V(B_1, , B_m, , B_q)$ (or V) being a complex nuance induced from N_i, then $V \in Neg_t^\rho(x, U)$ iff:*
L0: $\forall B_m$, $\exists A_h$ *such that: L00*: $B_m \in Neg_t(x, A_h)$, *L01* : $\forall z$, $\mu_{A_h}(z) \geq \rho \Longrightarrow \mu_{B_m}(z) \leq 1-\rho$, *L02* : $\forall z$, $\mu_{B_m}(z) \geq \rho \Longrightarrow \mu_{A_h}(z) \leq 1-\rho$.
L1: $\forall z$, $\{\mu_U(z) \geq \rho \Longrightarrow \mu_V(z) \leq 1\text{-}\rho\}$, *and* **L2**: $\forall z$, $\{\mu_V(z) \geq \rho \Longrightarrow \mu_U(z) \leq 1\text{-}\rho\}$.
Any $V \in Neg_t^\rho(x, U)$ is said to be a **linguistic negation** *of U* **applied to** x, **given** ρ *and the* **standard form** F_t.

Definition 5. *Let U and V be associated with the same concept, $Vo_x(U,V) = min\{\mu_U(x) \rightarrow_L \mu_V(x), \mu_V(x) \rightarrow_L \mu_U(x)\}$ where $\rightarrow_L$ is Lukasiewicz's implication. Let the neighborhood between U and V be: $Vo(U, V) = min_x Vo_x(U, V)$.*

Proposition 3. *If $V \in Neg_i^\rho(x,U)$ then $Vo(V,U) \leq 2(1-\rho)$*

Definition 6. *Knowing that $0.5 \leq \rho \leq 1$, the value $2\rho - 1$ defines the rejection strength associated with a property $V \in Neg_i^\rho(x, U)$.*

Proposition 4. $Neg_i^1(x, U) \subset Neg_i^{0.9}(x, U) \subset ... \subset Neg_i^{0.5}(x, U)$.

Example: *Using proposition 3, Vo("normal", "rather little high")=0.2, then* $\rho \leq 0.9$*, i.e., "rather little high" belongs at most to the subsets of* $Neg_i^{0.9}(x,$ *"normal"). For Q = "extremely high", Vo("normal",Q) = 0 means that* $\rho \leq 1$*, i.e. "extremely high" belongs to the subsets of* $Neg_i^1(x,$*"normal").*

Definition 7 (Second Preference Principle). *Given a standard form* F_t *and an expression "x is U", let* $\rho(V)$ *be the greatest* ρ *such that* $V\in Neg_t^{\rho}(x, U)$*. V is* **preferred to** *W for the negation of U if* $\rho(V) \geq \rho(W)$*.*

Example: *For the negation of "normal" in form* F_5*, "extremely high" is preferred to "rather little high". Since* $\rho($*"extremely high"*$) = 1$ *meanwhile* $\rho($*"rather little high"*$) = 0.9$*.*

The following properties result from previous definition of linguistic negation.

Proposition 5. *(1): Given* $U\in N_i^*$ *and* $V\in N_i^*$*:* $V\in Neg_t^{\rho}(x, U)$ *if* $U\in Neg_t^{\rho}(x, V)$*. (2): A complex nuance* $V\in Neg_t^{\rho}(x, U)$ *if: (2a):* $U=A\wedge B$ *with* $A\in N_i^*$ *and* $B\in N_i^*$*,* $V=P\vee Q$ *with* $P\in Neg_t^{\rho}(x, A)$*,* $Q\in Neg_t^{\rho}(x, B)$*,(2b):* $U=A\vee B$ *with* $A\in N_i^*$ *and* $B\in N_i^*$*,* $V=P\wedge Q$ *with* $P\in Neg_t^{\rho}(x, A)$*,* $Q\in Neg_t^{\rho}(x, B)$*.*

Proposition 6 (Contraposition Laws). *Let us suppose that the implication* $\rightarrow$ *and its associated T-norm T satisfy the properties:* $u\rightarrow v=1$ *iff* $u\leq v$ *;* $T(u\rightarrow v, v\rightarrow w)\leq u\rightarrow w$ *(weak transitivity law);* $u\rightarrow v=\neg v\rightarrow \neg u$ *(contraposition law). Then, the extended linguistic negation possesses the following properties:*
(i) If there exists $P\in Neg_t^{\rho}(x, A)$ *and* $Q\in Neg_t^{\rho}(y, B)$ *such that* $Q\subset \neg B$ *and* $\neg A\subset P$*, then the rule if "x is A" then "y is B" implies the rule if "y is not B" then "x is not A".*
(ii) If there exists $P\in Neg_t^{\rho}(x, A)$ *and* $Q\in Neg_t^{\rho}(y, B)$ *such that* $P\subset \neg A$ *and* $\neg B\subset Q$*, then the rule if "y is not B" then "x is not A" implies the rule if "x is A" then "y is B".*
(iii) If there exists $P\in Neg_t^{\rho}(x, A)$ *and* $Q\in Neg_t^{\rho}(y, B)$ *such that* $\neg A=P$ *and* $\neg B=Q$*, then the rules if "y is not B" then "x is not A", and if "x is A" then "y is B" are equivalent.*

Example 1. Let us suppose that:
P=(∨rather low ∨ very low extremely low)$\in Neg_2^{\rho}$(x, ∨(medium high)),
(∨ rather low ∨ very low extremely low) ⊂ ¬(∨medium high),
Q=¬vaccinated. In the rule R5 :"If the patient is not vaccinated, the inflammation due to the test is not medium or not high", the conclusion is translated into "the inflammation is rather or very or extremely low". By using previous proposition, this rule implies the rule "If the inflammation is medium or high then the patient is vaccinated".

5 Choice Strategy

We extend the *strategy* proposed in [3] to the negation of complex nuances:
1. First, select the negation form F_t according to linguistic statistics concerning the complex nuance U (assumption presented in 3)

2. Compute the set $Neg_t(x, U)$.
3. Select in $Neg_t(x, U)$, the complex nuances V such that $\rho(V)$ is maximum.
4. Among these complex nuances, use the first preference principle in order to make a choice.
5. Discriminate ex-aequo complex nuances by taking into account their complexity degrees. This last point is justified by Sperber and Wilson's simplicity principle [10].

6 The Model in Action

First of all, we are going to translate all negative complex nuances appearing in rules and facts. They concern the expressions: "temperature is not normal", "fat eating is not moderate", "risk of cholesterol is not weak", "temperature is not very low", "temperature is not very high", "the inflammation is not small", "the patient is not vaccineted" and "the inflammation due to mono-test is not moderate or high". Let us decompose the affirmative translation of the assertion "Temperature is not normal": according to linguistic statistics on the different forms of linguistic negation, this negation has the standard form F_2. So, let us calculate Neg_2(x, "normal"). This set contains all nuances of all properties associated with the concept "temperature" (except the precise nuance expression "$\emptyset$ normal"): Neg_2(x, "normal") = $N^*_{\text{temperature}} \setminus$ {"normal"}. Then we must select the properties having a maximal rejection strength. The following properties have a strength equal to 1: properties containing "high" or "low" without nuance, or with translation nuances greater than "rather", or with precision nuances greater than "more or less", or with combinations "really very", "really very very", "really extremely", and also the three properties "extremely little normal", "very very little normal" and "very little normal". Computing the statistical probability of all these nuanced properties, it appears that the best expression is "high". "Temperature is not very low" is translated into "Temperature is high". "Temperature is not very high" by the form F_2 leads to all nuances of "high", which finally gives "Temperature is little high". "Inflammation is not small" is translated into "Inflammation is medium or high" "Fat eating is not moderate", by the form F_3, leads to the nuances of "zero" "low" and high", and finally is translated into "Fat eating is high". "The cholesterol risk is not low" is translated into "The cholesterol risk is high". The rule R5 is translated as shown in example 1. Finally, we obtain:

IC1: The temperature is high, the eardrum color is really very red, fat eating is low, the tension is exactly normal.

IC2: The temperature is little high, the eardrum color is normal, fat eating is high, and the tension is normal.

IC3: The temperature is rather little high, the eardrum color is normal, fat eating is very low or really moderate, the tension is normal, and the inflammation due to the mono-test is medium or high.

R1: If the temperature is high and the eardrum color is very red, the disease is an otitis.

R2: If the temperature is *high*, the patient is ill.
R3: If fat eating is *high*, the cholesterol risk is *high*.
R4: If the cholesterol risk is high, a diet with no fat is recommended.
R5: If the inflammation due to the monotest is *medium or high* then the patient is *vaccinated*.

From index card 1, rule R1 can be fired, since according to Figure 2 "really very red" implies "very red", so we can infer that "The disease is an otitis". Rule R2 leads us to deduce that "The patient is ill". The other two rules can not be fired. From index card 2, rule R3 gives that "the cholesterol risk is high", then rule R4 leads us to recommend "a diet with no fat". By using rule R5, we can conclude that the third patient is vaccinated.

7 Conclusion

We have defined a general model of linguistic negation of assertions like "x is not U" in the fuzzy context. This approach to negation, in accordance with linguistic analysis pursues preceding works. The strategy of choice uses the rejection strength: one selects the complex nuances which belong to the strongest negations of the initial complex nuance then statistical information on the language and on the customs of the speaker are used.

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