Abstract — This paper first analyses NATO recommendations in information evaluation for Intelligence. Then it presents a definition of information evaluation which is based on the notion of correlation between two pieces of information. It also shows how an ontology can be used to estimate correlations. Finally, it presents a general process which computes information evaluation according to this definition and it shows that this process agrees NATO recommendations.

Keywords: Information fusion, information evaluation, ontology

1 Context and objectives

This paper addresses the problem of information gathering or, equivalently, the problem of fusion of information provided by several sources.

In Intelligence, several fusion nodes have to interoperate and cooperate, so NATO has elaborated a Standardization Agreements (STANAG) in order to define a common information evaluation system ([1], [2]). The aim of such an evaluation system is to indicate the degree of confidence that may be placed in any item of information which has been obtained for intelligence. According to NATO, this is achieved by adopting an alphanumeric system of rating which combines a measurement of the reliability of the source of information with a measurement of the credibility of that information when examined in the light of existing knowledge as follows.

According to NATO, reliability of the source is designated by a letter between A and F signifying various degrees of confidence and credibility of information is designated by a number between 1 and 6 signifying varying degrees of confidence. The complete STANAG is given in appendix.

It can be noted that these definitions, given in natural language, are quite imprecise and ambiguous and then they can be discussed. For instance, according to the previous recommendations, the reliability of a source is defined in reference to its use in the past but does not take into account its usage context i.e, the actual environment of use of this source.

As for the credibility of information, the rating defined previously does not qualify an unique property. For instance, how should we note an item of information supported by several sources of information which is also conflictual with some already registered information? According to these definitions, this item should be given a credibility rating of 1 and it should also be given a rating of 5. Furthermore, according to the recommendations, a rating of 6 should be given to an item whose truth cannot be judged. This supposes that the other ratings (1...5) concern the evaluation of the truth of information. If so, rating of 1 should be given to a true information. But, as it is defined, rating of 1 should be given to an item supported by at least two sources. This is questionable since, the different sources (even if they agree) may emit false information.

Previous works ([6], [7], [8], [11]) have tried to formalize the informal recommendations presented in section 2. They are all based on the fact that the three main notions which underline these informal recommendations are: the number of independent sources that support a piece of information, their reliability and the fact that pieces of information are or tend to be in conflict. In particular, [6] and [7] present a logical definition of evaluation based on the number and the reliability of the sources that supports a piece of information. The associated fusion method is weighted sum type and is an obvious extension of the majority method defined in [12] with Hamming distance between logical interpretations. [11] proves that this method implicitly takes into account degrees of conflict between pieces of information. These works assume that the information is described by using a logical language and they are based on an entirely automatic reasoning. In particular, they assume that the degree of conflicts between
two pieces of information is automatically computed.

In the present work, we would like to study another
approach in which information are more general (information will be reports written in natural language) and
which is, in some complex cases, not entirely automatic
since, in these cases, a human operator will be required to
give the degree of correlations between pieces of
information. However, for doing so, it will be helped by
means of an ontology, or more simply, by a hierarchy
of concepts. Our aim is to provide an approach which
is more general since it will take more general information
into account, but remains tractable in the sense that the comparison between pieces of information will
be left to the human.

This paper is organized as follows.

In section 2, we present a general architecture of a
fusion system. We also present a formal model for evaluating
information the main ingredients of which being the
reliability of the sources and the degree of correla-
tions between pieces of information. In section 3, we
show how an ontology can be used to help in instanci-
ating this model. In section 4, we discuss that model and
prove that it fits the informal recommendations of
NATO. Finally, section 5 is devoted to a discussion.

2 Our proposal

2.1 Architecture of the fusion system

The general architecture of the system we consider is
based on elements collectors. Each collector is a system
managed by an operator and which collects information
provided by one or several sources and/or one or several
other collectors. The main job of a collector is to update
the evaluation of each piece of information it collects.
It can also update the reliability of the sources with
which it is related to.

2.2 Information evaluation

In this work, pieces of information to be merged will
be reports written in natural language. They will not
be automatically analysed. There will be named
$I_1, I_2, \ldots, I_n$.

Pieces of information are emitted by sources. Each
source $S_i$ is associated with its degree of reliability $r(S_i)$
which is a real number belonging to $[0, 1]$ depending on
the fact that this source is judged more or less reliable
by the operator. Thus,

$$0 \leq r(S_i) \leq 1$$

Given two source $S_i$ and $S_j$. $r(S_i) < r(S_j)$ means that the operator thinks that $S_i$ is less reliable
than source $S_j$. $r(S_i) = 0$ means that the operator thinks that $S_i$ is not at all reliable. $r(S_i) = 1$ means that the operator thinks that $S_i$ is fully reliable.

In our model, each piece of information is associated
with its evaluation, denoted $v(i)$ which is a real number
between 0 and 1. Thus,

$$0 \leq v(i) \leq 1$$

2.3 Correlation between information

Let $I_1$ and $I_2$ be two different pieces of information.
Their degree of correlation, noted $\alpha_{I_1, I_2}$, is a real number in $[-1, +1]$ that we will associate (see section 3 to see how) with $I_1$ and $I_2$ so that:

$$\alpha_{I_1, I_2} = 1.$$ 

We would like that $\alpha_{I_1, I_2} < 0$ iff $I_1$ tends to contradict $I_2$
$\alpha_{I_1, I_2} > 0$ iff $I_1$ tends to confirm $I_2$
$\alpha_{I_1, I_2} = 0$ else.

It’s worth noticing that for any two pieces of informa-
tion $I_1$ and $I_2$, we don’t have the property $\alpha_{I_1, I_2} = \alpha_{I_2, I_1}$, since the notion of confirmation is not symet-
rical. Indeed, suppose we have $I_1$ and $I_2$ such that
$I_1 \Leftarrow I_2$. In this case, $\alpha_{I_1, I_2} > 0$ and possibly $\alpha_{I_2, I_1} = 0$.

2.4 Information evaluation updating in
a particular collector

The general process of information evaluation updating
is the following: each piece of information will enter
a collector with an initial evaluation. This evaluation
will be updated by the collector each time other pieces
of information will be collected. At a given moment
(when the evaluation is over a given threshold or when
needed), information and its updated evaluation will be
sent to another collector of a higher level.

Thus, at the level of a given collector, if a piece of
information is emitted by a source, then its initial eval-
uation is defined by the reliability degree of the source
that emitted it (plus some corrections due for instance
to the conditions of use of this source; see [4] for the
definition of different criteria for the qualification of a
piece of information). If a piece of information is pro-
vided by a collector of a less high level, then its initial
evaluation is the one that has been computed by that
less high level collector. This is formalized below.

Assume that the knowledge base of the considered
collector contains the following pieces of information:
$I_1, \ldots, I_{n-1}$ associated with their respective current
evaluation: $v_1, \ldots, v_{n-1}$.

Consider a new piece of information $I_n$ associated
with its evaluation $v_n$. Two cases may happen: $I_n$ has
been emitted by a source whose reliability is $r(S_n)$. In
this case, $v_n = r(S_n)$ (i.e the current evaluation of $I_n$
is defined as the degree of reliability of the source that
emitted it). Or $I_n$ is emitted by a collector of a less
high level. In this case, the evaluation $v_n$ is the one
computed by that collector by a similar process.
Let us denote $v_k^*$ the evaluation of any piece of information $I_k$ updated after the arrival of $I_n$.

We define the updated evaluation by:

$$v_k^* = \frac{\sum_{k' \in K_k} \left(v_{k'} \cdot \alpha_{I_{k'},I_k}\right) + (|K_k| - 1)}{2|K_k| - 1}$$

Where $K_k = \{k' : 1 \leq k' \leq n \text{ and } \alpha_{I_{k'},I_k} \neq 0\}$. Notice that:

$$0 \leq v_k^* \leq 1$$

This function is such that:

- If $I_{k'}$ tends to confirm $I_k$, then $v_{k'} \cdot \alpha_{I_{k'},I_k} \geq 0$ (since $v_{k'} \geq 0$ and $\alpha_{I_{k'},I_k} > 0$). Thus this factor increases the evaluation of $I_k$.
- If $I_{k'}$ tends to contradict $I_k$, then $v_{k'} \cdot \alpha_{I_{k'},I_k} \leq 0$ (since even if $v_{k'} \geq 0$, $\alpha_{I_{k'},I_k} < 0$). Thus this factor decreases the evaluation of $I_k$.
- If $\alpha_{I_{k'},I_k} = 0$, then $v_{k'} \cdot \alpha_{I_{k'},I_k} = 0$. Thus this factor does not modify the evaluation of $I_k$.
- If $k = k'$, then $v_{k'} \cdot \alpha_{I_{k'},I_k} \geq 0$ and increases the evaluation of $I_k$.
- If $v_{k'} = 0$ then $v_{k'} \cdot \alpha_{I_{k'},I_k} = 0$ and thus does not modify the evaluation of $I_k$.

**Definition.** We say that two pieces of information $I_k$ and $I_{k'}$ are equivalent in the database of a collector \{I_1, \ldots, I_n\} iff:

1. $\alpha_{I_{k'},I_k} = \alpha_{I_k,I_{k'}} = 1$
2. $\forall l = 1 \ldots n \quad \alpha_{I_{k'},I_l} = \alpha_{I_k,I_{k'}}$

**Proposition.** If two pieces of information $I_k$ and $I_{k'}$ are equivalent in the database of a collector, then $v_k^* = v_{k'}^*$, whatever $v_k$ and $v_{k'}$ are.

3 How to define correlations?

3.1 Automatic computation

In simple cases, correlation $\alpha_{I,I'}$ between two pieces of information $I$ and $I'$ can be computed automatically. For instance, suppose that the set of valid information that the system manage is finite; then for every possible pair of pieces of information, the correlation degree can be pre-defined. More generally, the way correlation degrees can be calculated is related to the way information are produced.

**Example.** The dating of an event related in a textual document can be done from the extraction of named entities corresponding to the pattern $m/d/y^2$, where $m = MM$, $d = DD$, $y = YYYY|YY$. Now suppose two dates $date_1$ and $date_2$ respectively defined by $\text{date}_1 = m_1/d_1/y_1$ and $\text{date}_2 = m_2/d_2/y_2$. For instance, the correlation between $\text{date}_1$ and $\text{date}_2$ can be given by:

$$\alpha_{\text{date}_1,\text{date}_2} = 1$$

$$\alpha_{\text{date}_1,\text{date}_2} = 0.9$$

$$\alpha_{\text{date}_1,\text{date}_2} = 0$$

3.2 Semi-automatic computation based on using ontology

In other cases, pieces of informations are too complex to have a correlation degree automatically calculated, that justifies the operation of an human for this evaluation. However, in order to help him a little bit more the user, we suggest to take into account some knowledge described in an ontology.

The idea is to first automatically compute the degree of similarity between two pieces of information as shown. The user is then required to define the degree of correlation between two pieces of information only if their similarity degree is high. This is shown below.

3.2.1 Semantic annotation of information

Information which are collected by the collector are reports written in natural language.

In order to automatize the computation of information evaluations, we suggest to define a single ontology and to associate each piece of information with an instance of this ontology by means of a semantic annotation system as shown.

Different techniques and tools of semantic annotation are available:

- Some techniques are entirely manual: the user himself (here it can be the operator or the sensors) associates annotations with elements to be annotated. [9], [10].
- Some techniques are entirely automatic: a system associates annotations with elements to be annotated, given a set of learnt patterns or an ontology [13], [14].
- Some techniques are semi-automatic: the user associates annotations with elements to be annotated by choosing these annotations among a set of annotations proposed by the system [15].

Finally, an annotation $i$ is a tuple $(V_i^1, \ldots, V_i^{|V_i|})$, whose each element $V_i^k$ is a value belonging to some class.

**Example** Consider for instance that the information to be collected are reports about urban demonstrations. The ontology that must be used to help annotation contains spatial information (the place of the demonstration, the course of the march), temporal information (begining and end of the demonstration . . .), and other information (number of participants, lists of organisations who decided the demonstration . . .).
In order to illustrate our model, consider a very simple ontology leading to annotations of the form (where, when, ... degree of conflict from the notion of degree of correlation). Let $I_1$ and $I_2$ be two different pieces of information.

3.2.2 Semantic similarity between two annotations

Given two annotations $i = (V^1_i, \ldots, V^m_i)$ and $j = (V^1_j, \ldots, V^m_j)$, the degree of semantic similarity between $i$ and $j$ is defined by:

$$s(i, j) = s_1(V^1_i, V^1_j) \oplus \ldots \oplus s_m(V^m_i, V^m_j)$$

where the $s_k$ are some functions of similarity on the classes of the $k^{th}$ values and $\oplus$ is a given aggregation function.

Example (continued). Let us take again the (where, when, who) annotations. Here, the three functions $s_1$, $s_2$ and $s_3$ respectively define the similarity between places, dates and people. Assume that these functions are such that:

- $s_1$(Etoile, Champs Elysées) = .99
- $s_2$(05-21-14, 05-21-15) = .99 and
- $s_3$(students, students) = 1

If function $\oplus$ is such .99 $\oplus$ .99 $\oplus$ 1 = .99 then

$s_1$(Etoile, 05-21-14, students), (Champs Elysées, 05-21-15, students)) = .99.

This means that according to these different functions, a report relative to a demonstration of students near Etoile on May 21st at 14pm and a report relative to a demonstration of students near Champs Elysées on May 21st at 15pm have very high semantic similarity.

After the annotation phase, we then have a set of information $I_1, \ldots, I_n$ with their respective annotation $i_1, \ldots, i_n$, which are instances of a common ontology.

Our objective is that the operator is required to give only the degrees of correlation of pieces of information $I_k, I'_k$ which are ontologically close i.e such that $s(i_k, i'_k)$ is greater than a given threshold $\gamma$.

This leads to the following algorithm:

1. $\forall k = 1 \ldots n \quad \alpha_{I_k, I_k'} \leftarrow 1$
2. $\forall k = 1 \ldots n \quad \forall k' = 1 \ldots n \quad k' \neq k \Rightarrow \alpha_{I_k, I_k'} \leftarrow 0$
3. $\forall k = 1 \ldots n \quad \forall k' = 1 \ldots n \quad k' \neq k$ the semantic similarity $s(i_k, i'_k)$ is computed.
4. If $s(i_k, i'_k) > \gamma$, then the information $I_k$ and $I_k'$ are transferred to the operator in order he estimates their degrees of correlation $\alpha_{I_k, I_k'}$ and $\alpha_{I_k', I_k}$.

Two pieces of information relative to the same place, the same date and the same persons are ontologically close and may contradict or confirm each other, whilst two information which are ontologically distant will keep a null degree of correlation.

Notice that the evaluation of the degrees of correlation by the human operator is necessary since two information semantically close do not necessarily confirm each other.

Example. For instance, the information “the demonstration has been followed by a huge number of students near Etoile on May 21st at 14pm” and the information “only few students in the streets nearby Champs Elysées on May 21st at 14pm” are ontologically close (see previously) but they are contradictory.

However, if a finer ontology had been used (that allows more semantically rich annotations), it would have been noted that the two information are not close.

4 Analysis of our proposal

The question we addressed here is now: is the model of information evaluation described in this paper agrees with the informal requirements of NATO?

We aim at proving that this model agrees them by showing that it takes into account the three main notions which underline these requirements which are the number of independent sources that support information, their reliability and the fact that pieces of information are contradictory or tend to contradict.

- The previous model obviously takes into account the number of independent sources that support a piece of information and their reliability. More precisely, the more supported an information is and the more reliable its sources are then the higher its evaluation is.

Indeed, for a given $k$, let us denote:

$$S^1_k = \{k' = 1 \ldots n, \alpha_{I_k, I_k'} > 0\}$$
$$S^2_k = \{k' = 1 \ldots n, \alpha_{I_k, I_k'} \leq 0\}$$

Thus we can write:

$$v^*_k = A + B(\sum_{k' \in S^1_k} v_{k'} \alpha_{I_k, I_k'}) + B(\sum_{k' \in S^2_k} v_{k'} \alpha_{I_k, I_k'})$$

where $A$ and $B$ are constants.

If the number of sources that support information $I_k$ increases, then $\sum_{k' \in S^1_k} v_{k'}$ increases. Thus, $v^*_k$ increases.

If the degrees of reliability of the sources that support $I_k$ increase, then $\sum_{k' \in S^2_k} v_{k'}$ increases. Thus, $v^*_k$ increases.

- The information evaluation model previously defined takes into account the fact that pieces of information are contradictory or tend to contradict.

Indeed, we can obviously define a notion of degree of conflict from the notion of degree of correlation. Let $I_1$ and $I_2$ be two different pieces of information.
Their degree of conflict, noted \( c_{I_1,I_2} \), can be defined by: 
\[
c_{I_1,I_2} = -\alpha_{I_1,I_2}.
\]
Notice that \( c_{I_1,I_2} \in [-1, +1] \).
It is thus obvious that:
\[
c_{I_1,I_2} = -1 \quad \text{if} \quad I_1 \text{ tends to contradict } I_2.
\]
\[
c_{I_1,I_2} > 0 \quad \text{iff} \quad I_1 \text{ tends to confirm } I_2.
\]
\[
c_{I_1,I_2} = 0 \quad \text{else}.
\]

## 5 Discussion

In this paper, we dealt with fusion of general kind of information such as reports written in natural language. We first defined a general architecture of a fusion system based on several connected collectors. We also showed how an ontology is useful to annotate the pieces of information and to define the degree of similarity between two pieces of information. We claimed that the operator of a collector must be required to examine pieces of information only when their degree of similarity is over a threshold. In this case, the operator has to assess their degree of correlation. In the model we defined, the degrees of correlation and the degrees of reliability of the sources are the ingredients of the evaluation of information. Finally, we showed that this model agrees with the informal requirements relative to information evaluation given by NATO in the sense that it takes into account the main notions which underline them.

The implementation of this general process is under development and it will lead to an experimental validation of the ideas.

However, one question concerns the choice of the different constants and functions used in the process such as:

- The value of the threshold of the information evaluation which conditions the transfer of a piece of information from a collector to a higher collector (threshold mentionned in section 2.4).
- The functions of similarity between values denoted \( s_i \) in section 3.2.2.
- The aggregation function denoted \( \oplus \) in section 3.2.2.
- The value of the threshold denoted \( \gamma \) in section 3.2.2.

At this present time, it is hard to estimate how the global information evaluations vary according to the choices of these functions and thresholds. Studying the impact of such choices on the resulting evaluation constitutes our future work.

### Appendix

According to NATO, reliability of the source is designated by a letter between A and F signifying various degrees of confidence as indicated below.

- **A source is evaluated A** if it is completely reliable. It refers to a tried and trusted source which can be depended upon with confidence.
- **A source is evaluated B** if it is usually reliable. It refers to a source which has been successfully used in the past but for which there is still some element of doubt in particular cases.
- **A source is evaluated C** if it is fairly reliable. It refers to a source which has occasionally been used in the past and upon which some degree of confidence can be based.
- **A source is evaluated D** if it is not usually reliable. It refers to a source which has been used in the past but has proved more often than not unreliable.
- **A source is evaluated E** if it is unreliable. It refers to a source which has not been used in the past.
- **A source is evaluated F** if its reliability cannot be judged. It refers to a source which has not been used in the past.

According to NATO again, credibility of information is designated by a number between 1 and 6 signifying varying degrees of confidence as indicated below.

- **If it can be stated with certainty that the reported information originates from another source than the already existing information on the same subject, then it is classified as “confirmed by other sources” and rated 1.**
- **If the independence of the source of any item of information cannot be guaranteed, but if, from the quantity and quality of previous reports, its likelihood is nevertheless regarded as sufficiently established, then the information should be classified as “probably true” and given a rating of 2.**
- **If, despite there being insufficient confirmation to establish any higher degree of likelihood, a freshly reported item of information does not conflict with the previously reported behaviour pattern of the target, the item may be classified as “possibly true” and given a rating of 3.**
- **An item of information which tends to conflict with the previously reported or established behaviour pattern of an intelligence target should be classified as “doubtful” and given a rating of 4.**
• An item of information which positively contradicts previously reported information or conflicts with the established behaviour pattern of an intelligence target in a marked degree should be classified as “improbable” and given a rating of 5.

• An item of information is given a rating of 6 if its truth cannot be judged.

References