High-level Fusion based on Conceptual Graphs

Claire Laudy
THALES Research & Technology
Palaiseau, France
claire.laudy@thalesgroup.com

Jean-Gabriel Ganascia
ACASA
Laboratoire d'Informatique de Paris 6
Paris, France
jean-gabriel.ganascia@lip6.fr

Célestin Sedogbo
THALES Research & Technology
Palaiseau, France
Celestin.sedogbo@thalesgroup.com

Abstract – Most of studies in the field of information fusion focus on the production of high-level information from low-level data. The challenge is then to fuse this high-level information to produce a global and coherent information. Another approach consists in interpreting data as high-level information and fuse it at once. Our approach relies on the use of Conceptual Graphs model. The model is widely used for knowledge representation. We propose to go further and use it for information fusion. Conceptual Graphs model contains aggregation operators such as join and maximal join. This paper is dedicated to the extension of the maximal join operator in order to manage heterogeneous information fusion. After describing the suitability of maximal join for high-level information fusion, we present the extension that we propose. The extension relies on relaxing the equality constraint on observations and on using fusion strategies. A case study illustrates our proposition.

Keywords: Graph-based Information Fusion, Conceptual Graphs, Ontology based modeling, High-level multi-source information fusion.

1 Introduction

The first step of the decision-making process is to get information in order to elaborate a decision from it. Such a process is difficult as information is distributed across various sources in different media. For example, a terrorist attack may be reported through news, SMS's, videos, etc. This makes the task of formatting all the pieces of information into a coherent and accurate global information awkward.

A lot of studies have been performed concerning the fusion of either low-level data or data expressed through the same media. For instance, [1] and [2] focus on fusion of images coming from different kinds of sensors. [3] proposes a method to fuse electromagnetic and acoustic data which are both low-level data. The resulting higher-level information must, nevertheless be fused to obtain to coherent global information. Our aim is to concentrate on high-level and heterogeneous information fusion. Therefore, low-level data coming form heterogeneous sources will be interpreted into high-level information. This high-level information is then fused at once.

The main issue is to integrate sources of information that are highly heterogeneous. Each one of these sources expresses information through a dedicated formalism and using an appropriate semantics. The heterogeneousness of information concerns the formalisms that are used and the level of semantics conveyed by each source. The media on which the information is communicated may also be different. Finally, the reliability of each source may differ.

The objectives of our work is thus to propose an approach and a framework dedicated to high-level and heterogeneous information fusion. By high-level information, we mean that our aim is to manipulate semantic objects. The objective is to transform low-level data into information enriched with knowledge concerning the type of the information source, its specificities and the media on which the information is conveyed. This level of abstraction allows us to ease the fusion process. Heterogeneous information items are transformed into a set of homogeneous data. Homogeneous data can then easily be manipulated thanks to common operators.

An important aspect of the work presented here is to find a formalism able to convey this level of abstraction. Furthermore, the formalism must tolerate different levels of details and precision, according to the different portions of information that are considered. This will allow to take advantage of all the available information sources. Ontologies are widely used to represent high-level information. Among others, the information fusion community uses ontologies to store domain knowledge ([4]). Our approach also relies on the use of ontologies as they have the previously cited properties. They allow modeling a domain in a structured and easily usable way. Different levels of details can be expressed through the definition of basic and complex concepts. The formalism that we propose to use is the conceptual graphs model.

Conceptual graphs [5] are a well known and widely used formalism for knowledge representation. The advantages of using graph structures, and particularly conceptual

graphs model, to represent information have been stated in [6]. The authors explain how criminal intelligence information and model can effectively be stored as conceptual graphs. They underline that, using such a model allows to reason and identify inconsistencies in the information. We propose to take advantage of this representation and go further by using the same model for information fusion.
Using the same model for both information representation and information fusion has a major advantage. It allows us to remove the bias due to the translation from one formalism to another when using distinct models.
Maximal Join is an aggregation operator on conceptual graphs. It allows the fusion of not strictly identical concepts. We propose to use it for high-level information fusion. It must nevertheless be extended. Observations may have different levels of detail or granularity, according to the source they come from. The extension that we propose overcomes the limitations encountered when fusing observations.
The genericity of the introduced approach allows to use it on any application where the domain knowledge can be expressed by experts. In the following sections of this paper, we illustrate our proposition using a case study that was developed on real data. This case study concerns the fusion of TV program descriptions. The purpose is to obtain more detailed, reliable and global descriptions of the TV programs.
Section 2 of this paper presents related works as well as the case study. The conceptual graphs formalism is described in section 3. Section 4 presents the maximal join operator on conceptual graphs. We detail its suitability for high-level information fusion. Section 5 details our proposition of extension for the maximal join. This extension relies on the use of external fusion strategies detailed in the same section. We then conclude and present future work.

2 Context

2.1 Related Work

Our aim is to use the output of intelligent sensors as input observations for our system. For textual information, these intelligent sensors are systems able to analyze the meaning of the texts and store it as machine readable information. As conceptual graphs were initially developed in order to analyze natural language, a lot of research exists ([7], [8], [9]), aiming at transforming textual information items into conceptual graphs. Considering other media, recent studies such as [10] and [11] have been realized. They aim at automatically analyzing images and videos and store the resulting descriptions into conceptual graphs. Finally, as stated in [12] and [13] conceptual graphs are widely used to formalize several domains of knowledge as different as biomedical risks or corporate modeling. Therefore, using conceptual graphs as common representation formalism for the storage of information coming from heterogeneous sources as well as for knowledge representation and domain modeling is a promising approach.
Considering the fusion process, several studies aim at fusing information containing a high-level of semantics. In [14], information items stored as graph structures are fused and compared to predefined libraries of situations. The main difference from our proposition is on the understandability of the representation knowledge. We claim that human experts have to supervise the fusion process. Therefore, the knowledge representation must easily be understood by common, which is a major concern of our proposition. Therefore, our proposition relies on the use of ontologies.
In [15] entities and relations are identified in information coming from heterogeneous sources (data bases, semantic web…). Co-references between entities are identified, which is, somehow, a fusion process. Nevertheless, the focus of this work is on entities themselves. Our aim is to identify interactions between objects, and thus relations between entities. Furthermore, the co-reference resolution is based upon the fact that entities have unique names which are known. In the situations we observe, this hypothesis cannot be assumed.

2.2 Case Study

The approach that we propose can be applied on any domain for which a model can be drawn a priori and stored as an ontology. Nevertheless, in order to validate it on real data, our results were applied on an intuitive case study. This case study concerns TV program descriptions. These descriptions have different levels of detail. They depict different points of view of the programs, according to the source from which they are extracted. The purpose of the study is to fuse the descriptions given by the different sources.
This domain was chosen to illustrate our approach because of the simplicity of the underlying model, the availability of real data and the numerous sources of information. Nevertheless, this case study raises several problems that are encountered in other more complex domains, such as the lack of observation on one source, observations of two close but different objects or different levels of details according to each source.
Our first source of information is an online TV magazine. Figure 1 depicts an extract of the information delivered by this source[1].
The descriptions given by the first source contain information about the scheduling of the programs, their titles and the channels on which they are scheduled. The description also contains detailed information about the content of the program itself. The content is described by a natural language textual description, a category of program, a list of actors, a list of presenters etc. This

[1] Both sources deliver XMLTV formatted observations (an XML format associated with a document type specific to TV programs description).

source describes all the TV programs scheduled on all the TV channels during one week starting from the current day. The TV program descriptions may be updated once a day. As adjustments on the TV programs diffusion often occur during the day, shifts often happen between scheduled times and real diffusion times.

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE tv SYSTEM "xmltv.dtd">
<tv source-info-url="http://telepoche.guidetele.com/" generator-info-name="XMLTV" >

 <channel id="C1.telepoche.com">
  <display-name>tf1</display-name>
  <icon src="http://static.guidetele.com/c_img/chaine/tf1.gif" />
 </channel>
[...]
 <programme start="20061127064500 +0100" stop="20061127083500 +0100" showview="5755621" channel="tf1">
  <title>TF! Jeunesse</title>
  <desc lang="fr">Franklin. Tabaluga. Dora l'exploratrice(sous-titrage télétexte).</desc>
  <category lang="fr">emission jeunesse</category>
 </programme>
[...]
</tv>
```

Figure 1: initial observation on telepoche.fr

The second source of information is the live stream of metadata associated with the video stream on the TNT (Télevision Numérique Terrestre), Cable or Satellite TV stream. Figure 2 shows an example of the information available on the DVB source.

```
<?xml version="1.0" encoding="ISO-8859-1" ?>
<tv generator-info-name="TSReader">
[...]
 <channel id="1537-TF1">
   <display-name lang="en">TF1</display-name>
   <transport-stream-ID>6</transport-stream-ID>
   <signal-info>-0.0 MHz</signal-info>
 </channel>
 <programme start="20061127063959" stop="20061127064753" channel="1537-TF1">
   <title>Jt matin</title>
   <desc> |-0.0 MHz</desc>
 </programme>
 <programme start="20061127064754" stop="20061127083027" channel="1537-TF1">
   <title>TF ! JEUNESSE</title>
   <desc>Au sommaire «Franklin». «Tabaluga». «Dora». «Bob l'éponge».|-0.0 MHz</desc>
 </programme>
[...]
</tv>
```

Figure 2: initial observation on TNT metadata

As for the online TV magazine, the TNT metadata stream gives descriptions of TV programs containing schedule and title information. Contrary to the first source, this second source delivers information about the technical characteristics of the audio and video streams. DVB stream delivers, for each TV channel, the descriptions of the currently playing program as well as the following one. The information on this source is constantly being updated. In particular, the scheduling times of the following programs are constantly adjusted.

Besides the wish of obtaining more complete descriptions of the TV programs, when fusing the information coming from these two sources, our aim is to get a better scheduling of the programs. The fused schedule should be as close as possible to the reality.

3 Conceptual Graphs

3.1 Conceptual Graphs formalism

Conceptual Graphs are a formal model based on Existential Graphs [16] and Semantic Networks [17]. JF Sowa introduced the model in [5]. Conceptual graphs are a model for knowledge representation integrating linguistic, psychological and philosophical aspects. This formalism is particularly well suited to represent knowledge in a media- and source- independent way. The model was conceived in order to develop a logical system able to represent natural language in a simple way. We briefly describe the model and introduce the way we will use it.

The conceptual graphs model is essentially composed of an *ontology* and the *graphs* themselves. The ontology defines the different types of concepts and relations which are used in the conceptual graphs. It defines a set of type labels as well as a type hierarchy. The type hierarchy defines a partial order over the type labels. It is divided in two sub-hierarchies: one defining the conceptual relation types and one defining the concept types. The concepts types correspond to the names of the different groups of entities that potentially exist in the external world. The entities can be, for instance, the agents of the situations, properties of these agents, actions performed by the agents or abstract entities.

A type label in the hierarchy can be either primitive or defined. A *primitive type label* is a name placed somewhere in the type hierarchy. A *defined type label* is associated with a conceptual graph that depicts its meaning.

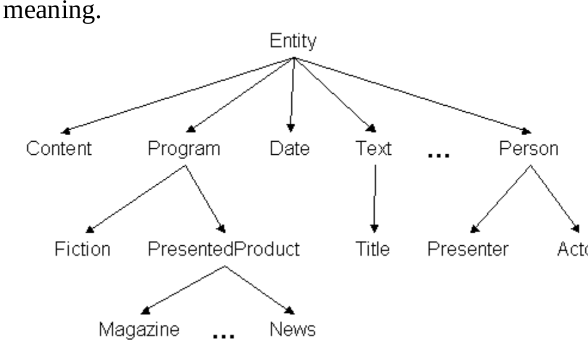

Figure 3: concept type hierarchy for TV programs

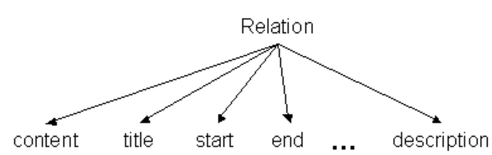

Figure 4: relation type hierarchy for TV programs

Figure 3 and Figure 4 depict a subset of the type hierarchy that was defined for the purpose of the TV program case

study. Figure 3 depicts the entities sub-hierarchy while Figure 4 depicts the relations sub-hierarchy.
The definition of the ontology that model the domain is the first step of the process of fusion. The modeling of the domain has to be completed with the definition of the set of situations that are expected to happen.
A conceptual graph is a graph with two kinds of nodes : *concepts* and *relations*. Arcs link couples of nodes in the graph. A conceptual graph is bipartite, which means that all arcs either go from a concept to a relation or from a relation to a concept.
A concept is always made up of two entities: the concept's type and the referent. The referent may be defined, blank or undefined (noted '*'). A concept with a defined referent is an *individual*, while one with blank or undefined referent is *abstract* or *generic*.
Relations relate concepts to each other. Relations have a relation type but no referent. The relation type indicates the kind of relation which links the two concepts.
There exists three forms for writing and using conceptual graphs: a display form, a linear form and a logical form. Figure 5 gives an example of a conceptual graph in the *display form*. The boxes represent concepts and the ovals represent conceptual relations. The display form is generally used to write graphs.

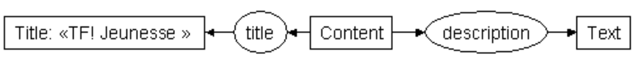

Figure 5: Example of conceptual graph

The *linear form* is close to the display form but is readable by machines. The linear form equivalent to the graph depicted in Figure 5 is the following:

[Content] –
-> (title) -> [Title: "TF! Jeunesse"],
-> (description) -> [Text]

Finally, conceptual graphs can be translated into *a logical form*. The logical form is used to reason and make inferences on conceptual graphs using logical operators.
The logical form for the previous example is the following one:

$\exists x, \exists y, \exists z\ (Content(x) \wedge Title(\text{"TF! Jeunesse"}) \wedge title(x, \text{"TF! Jeunesse"}) \wedge Text(z) \wedge description(x, z))$

In Figure 5, the concept [Title: "TF! Jeunesse"] is an *individual* concept as its referent is defined. The concept [Text] has no defined referent, therefore, [Text] is an *abstract*, or *generic* concept. It means that "there exists a text", but the identity or content of this text is unknown.
Figure 6 gives an example of a defined type label.

```
[PresentedProduct : x]  is
        [Content : x] – (presenter) -> [Presenter].
```

Figure 6: a defined type label

As one can express any set of concepts and conceptual relations using conceptual graphs, we propose to use them to formalize the business knowledge and store the observations coming from the information sources.

3.2 Canonical Graphs Basis

According to Sowa's definition, a *canonical graph* is a graph where concepts and relations are combined in a way that makes sense. That is to say that situations represented by canonical graphs are the ones that are plausible or have been perceived in the external world. The *canonical basis* is composed of the set of situations that are expected to occur in the external world and situations that happened. Potential interactions between the entities (defined as concepts and relations in the ontology) are represented using conceptual graph structures.
Defining the canonical basis is part of the domain modeling process. On the one hand, modeling the domain, consists in defining the situations that are expected to occur in the external world. On the other hand, acquiring the observations into the conceptual graph formalism, corresponds to adding the perceived situations to the canonical basis.
The canonical graphs representing the domain knowledge have the specificity of being "abstract". The concepts used to represent the domain knowledge have no referent as they are formed from general knowledge. They depict how the entities of the modeled world generally behave.
Figure 7 shows an example of an abstract canonical graph.

```
[Program] -
        -> (start) -> [Date]
        -> (stop) -> [Date]
        -> (original_language) -> [Language]
        -> (diffusion_language) -> [Language]
        -> (duration) -> [Duration]
        -> (content) -> [Content]-
                        -> (description) -> [Text]
                        -> (title) -> [Title]
                        -> (theme) -> [Theme]
        -> (diffusion_support) -> [Channel]
        -> (show-view) -> [ShowViewNumber]
```

Figure 7: TV Program Model

Contrary to the ones representing the domain knowledge, the graphs that store the observed information are (partially) instantiated graphs. The concepts representing individual entities are individual concepts. They have values corresponding to the states observed by the sensors.

```
[Program #0] -
      - (diffusion_support) -> [Channel = "tf1"],
      - (start)->[Date = "2006.11.27.06.45.00"],
      - (end)->[Date = "2006.11.27.08.35.00"],
      - (show-View)->[showViewNumber = "5755621"],
      - (content) ->[Content] - (title) -> [Title = "TF! Jeunesse"]
```

Figure 8: Observation on telepoche.fr

Figure 8 and Figure 9 show examples of observations given by the online magazine and the TNT metadata stream. Both are stored in the form of two conceptual graphs.

```
[Program #0] -
    - (diffusion_support) -> [Channel = "tf1"],
    - (start) -> [Date = "2006.11.27.06.47.54"],
    - (end) -> [Date = "2006.11.27.08.30.27"],
    - (content) ->[Content] – (title) -> [Title = "TF ! JEUNESSE"]
```

Figure 9: Observation on TNT metadata stream

3.3 Conceptual Graphs operators

New graphs can be derived from this canonical basis using canonical operations. These graphs express other views of the external situation. There are four canonical operations that allow to derive a canonical graph from other ones: copy, restriction, simplification and join. These operations and the ones relying on them will constitute the major part of the fusion process. Using canonical operations for fusion will guaranty that the graphs representing the fused information make sense.

- Applying the *copy* operation on a graph results in the exact copy of that graph.
- The *restriction* operation can replace the type of a concept with one of its subtypes. It can also convert a generic concept into an individual one.
- If a relation is duplicated in a conceptual graph, *simplification* can be applied in order to delete one of the duplicated relations.
- The *join* operation merges identical concepts and deletes redundant relations.

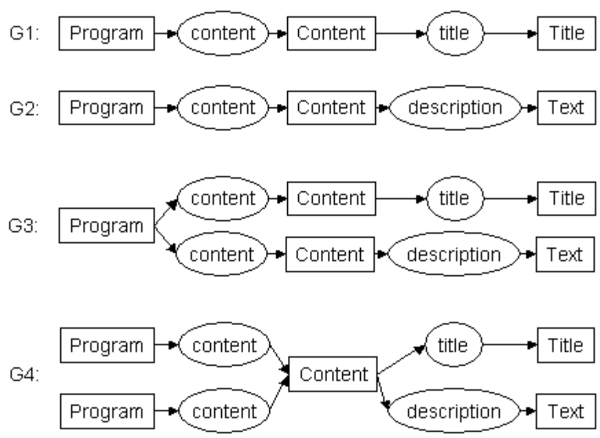

Figure 10: Example of Join operation

The join operator is a fusion operator. Two identical concepts are merged into a single one. Applying the join operation on two graphs may result in a set of joined graphs. The different results depict the choices that are made about the concepts that are fused or not. Figure 10 gives an example of join operation. Graphs G1 and G2 are joined to result either in graph G3 or in graph G4. In G3 the two [Program] concepts are fused, whereas, in graph G4 the two [Content] concepts are fused.

The following sections are dedicated to the extensions of this join operation. The aim is to fused as much compatible observations as possible.

4 Maximal Join as fusion operator

The following step is to go from fusion of two identical elements to the fusion of a set of compatible elements. Join operator aims at assembling two identical entities into a single one. The aim of fusion is to build a new entity from two different but compatible ones. Furthermore, intuitively, when fusing two graphs, one would like to fuse as much concepts as possible. Maximal Join is another operation defined on conceptual graphs. It extends the join operation in the sense that not only two, but the maximum of concepts, are fused between two graphs. To define the maximal join operation, Sowa defines several other operations.

Definition
If a conceptual graph u is canonically derivable from a conceptual graph v, then u is called a *specialization* of v and v is called a *generalization* of u.

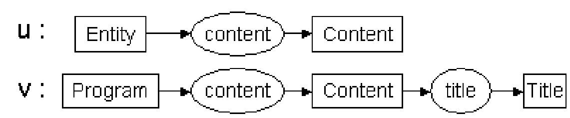

Figure 11: specialization / generalization

Definition
A *projection* of a conceptual graph v in a conceptual graph u is a function P of the nodes such as:

- the arcs and their labels are preserved,
- the labels of the nodes (concepts and conceptual relations) can be specialized.

Definition
Let two conceptual graphs u1 and u2 have a common generalization v with projections P1: v→u1 and P2: v→u2. P1 and P2 are *compatible projections* if, for each concept c in v, the following conditions are true:

- P1(c) and P2(c) have a common subtype,
- the referents of P1(c) and P2(c) conform their most general common subtype,
- the referents of P1(c) and P2(c) are either equal or one of them is undefined.

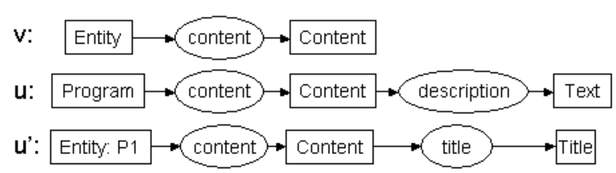

Figure 12: Compatible projections

The definition of the maximal join of two graphs u1 and u2 is the following one.

Definition

Let v be the most general common generalization of the graphs u1 and u2. There is no generalization v2 of u1 and u2 such as v is a sub-graph of v2.

P1 and P2 are two compatible projections of v in u1 and u2. P1 and P2 are *maximally extended* (P1 and P2 are maximally extended if they have no extension).

A join on these projections is called a *maximal join.*

As there may exist several maximally extended compatible projections between two graphs, joining two graphs maximally may give several results.

An intuitive algorithm to construct the maximal join of two graphs is described below. The first step consists in choosing one concept in each one of the two graphs. A join operation is realized on these concepts. The join is then extended on one relation at a time. The candidate relations for this extension are chosen in the neighborhood of the already joined concepts. When joining maximally two graphs, there may be as much results as maximally extended compatible projections.

Unlike simple join, maximal join allows to join not strictly identical but compatible concepts. The result of maximal join operation on two concepts [A: a] and [B: b] is the concept [C: c] were the type C is the most general common sub-type of A and B and c is equal to a (respectively b) if B (respectively A) is generic. Otherwise, a, b and c are equal. The result must ensure that there is no contradiction between the referents and values, nor between the result, the canon, the set of individuals and the ontology.

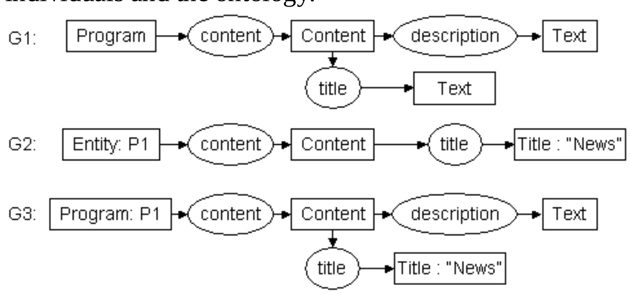

Figure 13: Example of Maximal Join operation

Figure 13 gives an example of maximal join operation. The result of the maximal join between G1 and G2 is the graph G3. In this example, [Program] and [Entity: P1] were joined to result in [Program: P1] and [Content] and [Content] were joined too.

Maximal Join is a major actor in the process of fusion among conceptual graph structures. There may be several possibilities of fusion between two observations, according to which combinations of observed items are fused or not. This phenomenon is well manage by the maximal join operator, as joining two graphs maximally result in a set of graphs, each one of it being a fusion hypothesis.

5 Towards a Framework for Information Fusion

5.1 Extending Maximal Join operator

Maximal join is a fusion operator. Nevertheless, it has to be modified in order to manage observations coming from different sensors. These observations may depict different points of view or different levels of detail and abstraction. Therefore, the information items that have to be fused may be different, although they depict the state of the same external object. The values of the concepts may be different while representing several observations of the same object by several points of view.

Figure 14 and Figure 15 give examples of such cases.

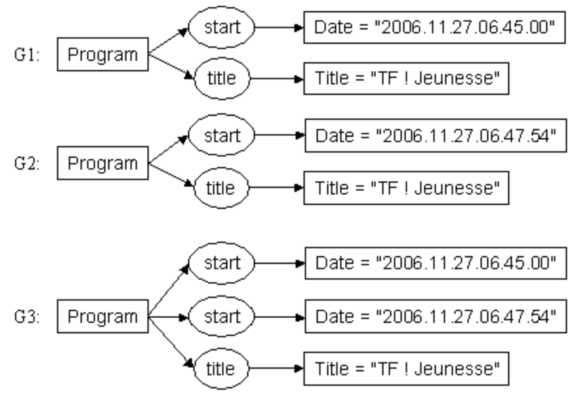

Figure 14

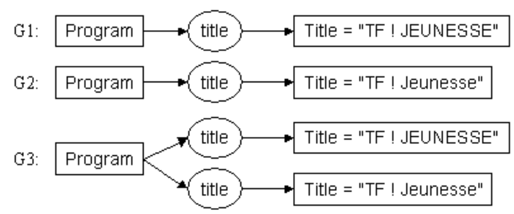

Figure 15

In Figure 14, the maximal join of the two graphs G1 and G2 result in the graph G3. The two concepts [Date: "2006.11.27.06.45.00"] and [Date: "2006.11.27.06.47.54"] cannot be joined using the standard maximal join operator as their values are different. However, because we know the domain that is modeled here (descriptions of TV programs), we have clues to say that the two concepts still represent the same entity in the observed world. A TV program has only one beginning time and there are often slight differences between the beginning times given by different sources. In such cases, the standard maximal join operator will not allow the fusion of the observations. Domain knowledge must be added in the maximal join operation in order to extend the notion of compatibility between concepts. Therefore we propose to relax the constraint of strict equality of values during the maximal join operation of two concepts. The notion of compatibility between concepts in the maximal join operation is extended from compatible conceptual types to compatible referents and individual values. The domain knowledge necessary to this extension is stored as compatibility rules that are called *Fusion Strategies.*

As the graphs modeling our domain have the property of having few relations in respect with the number of concepts, we propose to use a maximal join algorithm centered on relations. This choice allows the removal of most of the inconsistent fusion hypothesis during the first steps of the algorithm. To join two graphs maximally, we start by joining them on two relations. Then the join is extended on one relation at a time. The candidate relations for this extension are the ones neighboring the already joined relations and concepts. To join two relations, we test the equality of their conceptual relation types. Then we join the couples of source and target concepts.

Our proposition to extend the maximal join operation only interferes during the join of two concepts. Thus, the global maximal join algorithm remains unchanged. We introduce the notion of fusion strategy that are used during the join operation. As for the standard maximal join, the extended maximal join results in a set of graphs. Each resulting graph is a fusion hypothesis.

5.2 Fusion Strategies

As explained before, the notion of compatibility between concepts in the maximal join operation has to be extended in order to support information fusion. We call fusion strategies the set of operations allowing to test concepts compatibility and find the resulting fused individual concept. These strategies are defined in parallel of the extended maximal join operation. Most of the times, they will depend on the domain knowledge. Fusion strategies allow the introduction and use of domain for fusion.

Fusion strategies may depend on the domain knowledge to determine the value of a threshold for instance. They can also express the reliability one grants the different sources of information. For instance, this would result in choosing the value of the most reliable source as resulting fused value, without examining the values of the other sources. Fusion strategies may also combine domain knowledge and source reliability: each source reliability may depend on the type of the observed agent or event.

The most simple fusion strategy is the rule expressing that two entities can be fused only if they are strictly identical. The fusion part of the process would then be left to a human expert. Fusion strategies integrating domain knowledge and operator's preferences are the intelligent part of our fusion system. These strategies are implemented as rules taking conceptual graphs and conditions on the concepts referents and values as premises and resulting in a conceptual graph integrating functions to define its concepts values and referents as conclusion. According to the level of "intelligence" that a specific operator wants to leave to the system, the fusion strategies may include more or less sophisticated functions.

Concerning our case study, we imagined that the results of the fusion process could be used as input for a recording system. The programs that have to be recorded are the ones corresponding to the observed descriptions. Among others, the strategy depicted by Figure 16 and Figure 17 is defined. The fusion of graphs G1 and G2 results in graph G3. The fused starting time is the earliest one and the ending time is the latest one.

This strategy includes rules for fusion of titles, channels etc. We will not detail all the rules here. The values of these concepts being textual, the fusion strategy is based upon string comparisons.

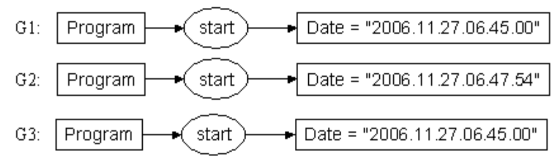

Figure 16: fusion of beginning hours

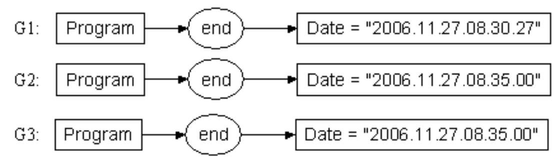

Figure 17: fusion of end hours

The result of the fusion process on the previous observation examples is given in Figure 18.

[Program #0] -

- (show-View) -> [showViewNumber = "5755621"],
- (start) ->[Date = "2006.11.27.06.45.00"]
- (end) -> [Date = "2006.11.27.08.35.00"],
- (content) -> [Content] – (title) -> [Title = "TF! Jeunesse"],
- (diffusion_support) -> [Channel = "tf1"],

Figure 18: result of the fusion process

Once the fusion process has been applied, the abstract canonical graphs introduced in 3.2 are used as filters to ensure that the results of the fusion process are consistent and have a meaning in the modeled world. This is done by comparing the fused graphs to the abstract ones. Projection operation on graphs is used.

6 Conclusion

This paper proposes to use the conceptual graphs model in the information fusion domain. We detailed the suitability of conceptual graph structures for domain knowledge representation and observations storage and manipulation. The model conveys a high-level of abstraction. that allows to enrich information with knowledge concerning its source and the media on which it is conveyed. Heterogeneous information can thus be manipulated as a set of homogeneous information. The complex concept definition process allows the manipulation of observations at different levels of description.

We proposed to realize the fusion process using the conceptual graphs model as well. Using the same model for information representation and information fusion avoids the bias due to the translation from one formalism to another one. We detailed the extension that we proposed for the maximal join operator. This extension allows to fuse not strictly identical observations. It is based on the use of domain knowledge to relax constraints when aggregating concepts. The standard maximal join is only based on structures and types compatibility. The extended version introduces the notion of fusion strategy. Fusion strategies are rules that allows to add a domain dependent notion to the fusion process.
The approach is generic as it can be applied to any domain that can be modeled thanks to a conceptual graphs ontology. A case study was developed in order to illustrate and validate our approach on real data.
Current and future work will first deal with the study and improvement of fusion strategies. Then, they will be applied to the improvement of the fusion framework. In particular, we will focus on temporal aspects and on the use of the reliability on the information sources in fusion strategies. The case study is currently being extended in order to compare several fusion strategies and their appropriateness to specific cases of information fusion. Furthermore, as the currently implemented fusion strategy is local to the fusion of one single couple of relations, the introduction of a global fusion strategy is being studied. This global fusion strategy will allow, among others, to determine if several observations relate to the same object in the external world. It will thus determine if the observations have to be fused using a local strategy and play the role of correlation operator among observations.

References

[1] M. Hanif, U. Ali, *Optimized Visual and Thermal Image Fusion for Efficient Face Recognition*, 9th International Conference on Information Fusion, Florence, Italy, 2006.

[2] R. S. Blum, *Minimax robust image fusion using an estimation theory approach*, 8th International Conference on Information Fusion, Philadelphia, PA, July 2005.

[3] E. Dalberg, A. Lauberts, R. Lennartsson, M. Levonen, L. Persson, *Underwater target tracking by means of acoustic and electromagnetic data fusion*, 9th International Conference on Information Fusion, Florence, Italy, 2006.

[4] C. Matheus, M. Kokar and K. Baclawski. *A Core Ontology for Situation Awareness.* 6th International Conference on Information Fusion, Cairns, Queensland, Australia, 2003

[5] J. F. Sowa, *Conceptual Structures. Information Processing in Mind and Machine*, Addison-Wesley, Reading, MA, 1984

[6] R. N.Reed, and P. Kocura, *Conceptual Graphs based Criminal Intelligence Analysis,* International Conference on Conceptual Structures, 2005

[7] P. Zweigenbaum, and J. Bouaud., *Construction d'une représentation sémantique en Graphes Conceptuels à partir d'une analyse LFG,* 4ème Conférence sur le Traitement Automatique des Langues Naturelles, Grenoble, France, 1997.

[8] J. Villaneau, J-Y. Antoine, and O. Ridoux, *LOGUS : un système formel de compréhension du français parlé spontané-présentation et évaluation*, 9ème Conférence sur le Traitement Automatique des Langues Naturelles, Nancy, France, 2002.

[9] M. Montes-y-Gomez, A. Gelbukh, A. Lopez-Lopez, *Text mining at detail level using conceptual graphs*, 10th international conference on conceptual structures, Borovets , Bulgaria, 2002.

[10] P. Mulhem, and W. K. Leow, and Y. K. Lee, *Fuzzy Conceptual Graphs for Matching Images of Natural Scenes,* 7th International Joint Conference on Artificial Intelligence, Seattle, Washington, USA, 2001.

[11] M. Charhad, *Modèle de Documents Vidéo basés sur le Formalisme des Graphes Conceptuels pour l'Indexation et la Recherche par le Contenu Sémantique,* Thèse de L'université J. Fournier, Grenoble, 2005.

[12] F. Volot, and M. Joubert, and M. Fieschi, *Knowledge and Data Representationwith conceptual graphs for Biomedical Information Processing : a Review,* Methods Inf Med. , N°37 pp. 86-96, 1998.

[13] O. Gerbe, and B. Guay, and M. Perron, *Using Conceptual Graphs for Methods Metamodeling*, 4th International Conference on Conceptual Structures, Bondi Beach, Sydney, Australia, 1996

[14] J. T. Rickard, *Level 2/3 Fusion in Conceptual Spaces*, 9th International Conference on Information Fusion, Florence, Italy, 2006.

[15] J. Starz, B. Kettler, P. Haglich, J. Losco, G. Edwards, and M. Hoffman, *The Concept Object Web for Knowledge Management*, 4th international semantic web conference, Galway, Ireland, 2005

[16] C. S. Pierce, *Collected papers of Chalres Sanders Pierce*, volume 2, C. Hartshone & P. Weiss (Eds.), Cambridge, MA, 1932.

[17] F. Lehman, *Semantic Network in Artificial Intelligence*, Pergamon Press, Oxford, UK, 1992.