Architecture of Knowledge Fusion within an Integrated Mobile Security Kit

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Abstract – *A common challenge for applications requiring information and knowledge fusion is the conversion of data streams into knowledge adapted to the context of usage. In the context of the project Integrated Mobile Security Kit, this paper focuses on the knowledge fusion sub-system. It integrates different fusion aspects based on a common domain model and embedded into a distributed and mobile infrastructure. The fusion aspects considered are attribute and situation fusion, situation recognition and event correlation. The main contribution of the paper are (1) the architecture of the knowledge fusion sub-system, (2) the domain model for integrating the fusion aspects and (3) the specification of the inner workings of the three different fusion aspects.*

Keywords: Knowledge fusion, Ontologies, Conceptual Graphs, Attribute fusion, Knowledge modeling, Event correlation.

1 Introduction

During the last decade, advancements in the areas of information technology and micro-electronics have opened the avenue to new applications exploiting real-time, semi-structured information and digital media in new types of applications. Examples are solutions for ambient assistant living, smart factories, intelligent logistics or civil security. A common challenge in these applications is the conversion of data streams into knowledge adapted to the context of usage. Knowledge fusion addresses this challenge and has been described as *'to be able to combine knowledge from disparate sources in a highly dynamic way'* [1]. Data fusion, information fusion and knowledge fusion are tightly related. The work of [2] describes the extension of the traditional perspective of data- and information fusion to knowledge fusion *'to emphasize the real-time integration and use of information from heterogeneous civilian and military sources to assist the human process of knowledge creation'*.

Within the field of knowledge fusion, this paper focuses on a specific aspect: the architecture of a knowledge fusion sub-system integrating different fusion aspects based on a common domain model embedded into a distributed and mobile infrastructure. The fusion aspects considered are attribute and situation fusion, situation recognition and event correlation. The main contributions of the paper are (1) the architecture of the knowledge fusion sub-system, (2) the domain model for integrating the fusion aspects and (3) the specification of the inner workings of the three different fusion aspects.

The remaining part of the paper is structured as follows: Section 2 introduces the application context by introducing the IMSK project. Section 3 presents the specification of the domain model used in our knowledge fusion approach. The domain model forms the basis for attribute and situation fusion, situation recognition and event correlation. These three fusion aspects are presented in sections 4, 5 and 6, respectively. Section 7 summarizes the work and offers an outlook to future work.

2 Application context

2.1 The IMSK project

The content of this paper is based on work achieved within the FP7-Security-IP Integrated Mobile Security Kit (IMSK) project (http://www.imsk.eu). IMSK is addressing the continuously evolving threat of unpredictable terrorist activity, which demands the application of existing and developing technology for the protection of citizens. More concretely, IMSK combines technologies for area surveillance, checkpoint control, CBRNE detection and support for VIP protection, into a mobile system for rapid deployment at venues and sites which temporarily need enhanced security. The project's approach is to design a system (IMSK) that will integrate heterogeneous information to provide a common operational picture. This includes to employ legacy and novel sensor technologies, and to adapt the system to local security forces.

The IMSK project started in spring 2009 and will last 4 years. It has the following objectives:

- Increase security through innovative sensors for threat detection and validation with low-false alarm rate, continuous monitoring, tracking / tracing of individuals, goods and vehicles.

- Increase situation awareness based on data fusion.
- Increase flow rate through security checks.
- Reduce personnel requirements and operator workload.
- Preserve personal integrity with non-intrusive operations.
- Provide integrated capabilities independent of local rules of engagement.
- Ensure timely and effective delivery of information through a novel use of communication infrastructures.

Data- and information fusion have major roles within the IMSK system. IMSK integrates different kinds of sensors providing observations of the sites to be protected. The data provided by physical sensors, as well as pieces of information provided by human observers and open sources, have to be combined in order to provide an overview of the ongoing situation.

Within this work, we are particularly interested in knowledge fusion and fusion of high level information. We decompose the fusion process into several phases of fusion. First, entities of the world are represented using detailed observations provided by different kinds of sensors. This is the *attribute fusion* phase. Then, the recognized entities are combined and relations among them are observed. The *situation fusion* phase aims at reconstructing a more global view of the observed situation that contains both the entities recognized in the attribute fusion phase and the relations that have been observed among them by other information sources providing information of a higher level. Both the attribute and situation fusion, rely on the same approach. The two phases differ only by the level of detail of the observations that are processed.

Once the representation of an ongoing situation is achieved, the *situation recognition* aims at deciding whether the ongoing situation is one of the "critical situations" preliminary defined by the end users. Last, the *event correlation* phase allows for combining the different static critical situations recognized in order to detect the occurrence of complex critical situations. The event correlation phase allows taking into account time and space issues of the critical event detection process.

Several scenarios were defined within the IMSK project, that aim at showing the adaptability of the platform to different types of environments and events. Within this paper, we use one of these scenarios to illustrate our proposition. The aim is the protection of VIPs during an EU summit. The events of the summit take place in three different locations of a city. The participants have thus to go from one place to another one. We focus on the protection of VIPs when crossing a bridge that is needed when going from the congress center to the dinner place. Several sensors are deployed in order to detect CBRN threats, fireworks, approaching vehicles, etc.

Our aim, within knowledge fusion, is to combine observations acquired through the different sensors (and potentially already fused at a low level), with information coming from other sources. We then have to detect potential critical situations and events, according to the ones that are specified by the end users of the IMSK system. Our example here focuses on the detection of a vehicle approaching a VIP while he/she crosses the bridge. We use the vehicles tracking system observations, the schedule of the summit and observations provided by people on the site.

2.2 The knowledge fusion sub-system

All knowledge representation models are divided into semantic-based and logical models (see Figure 1). The former describes the structure of the domain of discourse by formalizing objects and relations between them. The latter uses formalisms based on logical calculi to represent the domain.

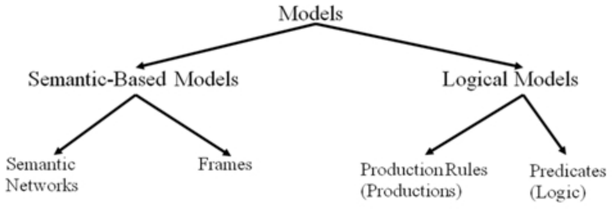

Figure 1: Classes of knowledge representation models

Within IMSK, semantic based models are of interest when implementing functionality such as critical situation recognition (see section 5). Furthermore, some abilities of logical models are required for implementing event correlation (see section 6). Thus, we propose to use a combination of semantic-based models with logical models, which for example is provided by many ontology languages.

Among the knowledge fusion approaches, the KRAFT approach [1] seems to be the most used one and the KS-Net approach [3] the most scalable one. The general idea is to capture the domain under consideration in a domain ontology and the tasks to be supported in task ontologies being a part of the domain ontology. Integration of the knowledge sources by using these ontologies and fusing the relevant knowledge on-demand inspired the proposed functionality for knowledge fusion within IMSK.

However, changes of this general idea were made regarding the task ontologies. They will be applied in a modified manner during design time by using ontology design patterns reflecting the different tasks and the way knowledge fusion is implemented, i.e by continuously converting sensor observations into facts which are then used instantly for fusion instead of performing the fusion on demand.

The overall architecture of the knowledge fusion subsystem is presented in figure 2. The core element in knowledge fusion sub-system is a knowledge base consisting of two main components: (1) a conceptual model capturing the domain knowledge relevant for knowledge fusion, and (2) the knowledge base collecting facts about the operative environment under consideration. The behavior of the knowledge fusion sub-system is controlled by predefined fusion models, including critical situation models (CS), event correlation models (EC) and attribute fusion models (AF).

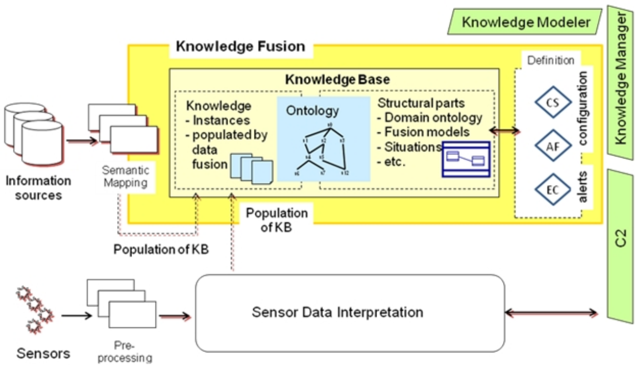

Figure 2: Architecture of the knowledge fusion module

The different fusion models as well as the conceptual model of the knowledge base are defined during design time. The graphical user interface for this functionality is called knowledge modeler in figure 2. During runtime of the IMSK system, changes in the actual configuration of the knowledge fusion sub-system and inquiries to the knowledge base are supported.

Furthermore, there are two interfaces to the neighboring sub-systems of the knowledge fusion modules:

- The *population of the knowledge base* is the purpose of interfaces to the sensor data interpretation and the semantic mapping of information sources.
- The *visualization* of fusion results and alerts is the purpose of the interface to the Command and Control (C2) system.

The knowledge base containing the domain knowledge is described in section 3. The processing modules are described in section 4 for attribute and situation fusion, section 5 for critical situation recognition and section 6 for event correlation.

3 The domain Model

3.1 A common domain model

Modeling the application domain allows sharing both a common vision of the aim of the application and the specificities of the domain among the different modules of the IMSK system, as well as among the different end-users of the system. Domain modeling also provides the knowledge necessary in order to process the incoming information, understand it and make useful decisions regarding the ongoing situation.

Within IMSK, the domain modeling and knowledge representation relies on the use of ontologies. They are used as the core representation paradigm and formalism. We take benefit of the progress that has been achieved regarding standardization with respect to semantic technologies.

The knowledge representation for the fusion module includes two main categories of knowledge: (1) knowledge specifying fusion tasks and (2) knowledge forming the input for these fusion tasks. Regarding the fusion task, we can differentiate between 3 task categories, which are all based on the same domain model:

- Attribute and situation fusion,
- Critical situation recognition,
- Event correlation

3.2 Structure of the domain model

The domain model contains the set of all the classes of participants that can be part of the situation observed by the IMSK system. For instance, the domain model contains classes of participants such as “Person”, “Building” etc. It also contains the set of all the classes of events that should be monitored, according to the application domain and the needs of the end users. For instance, events such as “Summit”, “Meeting (between persons)”, and “Demonstrations” are described in the domain model. The properties and “part-of” relations of the different classes of participants and events are specified as well as all the different types of relations that may be observed among participants and events. These relations may be geographical relations (for instance, a person being inside a building or a road being close to a building), or any other type of semantic relations depending on the application domain.

The domain knowledge is provided as an ontology whose structure can be expressed as a 5-tuple $O = (\mathcal{C}, \mathcal{R}, \mathcal{H}, \mathrm{rel}, \mathcal{A})$, consisting of

- two disjoint sets $\mathcal{C}$ and $\mathcal{R}$ whose elements are called concepts and relations respectively.
- a directed relation $\mathcal{H} \subseteq \mathcal{C} \times \mathcal{C}$ which is called *concept hierarchy*. $\mathcal{H}(C_1, C_2)$ means that C_1 is a subtype of C_2.
- a function $\mathrm{rel} : \mathcal{C} \times \mathcal{C}$, that relates concepts non-hierarchically.
- a set of ontology axioms $\mathcal{A}$, expressed in an appropriate logical language.

3.3 Ontology & structural patterns

We use predefined patterns in order to speed up the development and configuration process of both the domain model and the knowledge base of the knowledge fusion subsystem. Ontology design patterns provide a way of representing reusable knowledge of the IMSK domain. An ontology pattern is a set of ontological elements, structures or construction principles that intend to solve a specific engineering problem and that recur, either exactly replicated or in an adapted form, within some set of ontologies or is envisioned to recur within some future set of ontologies. Two types of patterns are of particular interest: *structural*- and *content* patterns.

Structural patterns deal only with the logical structure of the ontological elements but not with the actual ontology represented by these. A structural pattern is only a logical vocabulary with an empty signature, so no actual concepts and relations or other axioms are actually present. *Content patterns* are a specialization of structural patterns, since they both constrain the logical structure of how the solution to the problem should be modeled and set requirements on the ontological content. Content patterns are instantiations, and possibly combinations, of structural patterns where the signature is no longer empty.

4 Information Fusion

The attribute fusion and the observation fusion phases rely on the same approach. Within the attribute fusion phase, the different features acquired through the various sensors of IMSK are combined so to determine the identity of the objects and entities taking part of the external situation. As opposed to *kinematic information* (i.e. position, velocity and acceleration), *attribute information* provide descriptive information about an entity's characteristic or quality. The *ID-tag*, *color*, *width* or *acoustic signature* on an entity all make plausible attributes. Attributes are, by many means, useful within systems such as IMSK. In crowded spaces, attributes can facilitate a tracker to associate observations to correct tracks. A rich set of attributes can also support in the situational- and behavioral analysis, e.g. by determining the identity of entities, by establishing their relations, and by indicating odd attribute combinations.

The aim of the attribute fusion module is to build a more precise and complete description of the entities taking part in an observed situation. This is made by continuously trying to extend and refine the flora of attributes associated with each entity. For this task, we use heterogeneous sensors and take advantage on their different qualities and the kind of attributes they can deliver.

During the situation fusion phase, the focus is on the relations that exist between these different entities. Finding these relations allow having a more coherent representation of the ongoing situation. The representation goes from a set of observed entities to a structured observed situation in which the previous entities take part, with specific roles. When two observations (at least partially) overly, the information fusion sub-processes builds an unique view of the observed object or situation from them. The fusion phase confronts several points of view on the state of an object or a situation. This confrontation leads to a conflict resolution phase. A major stake of information fusion is to automate the conflict resolution phase.

We use the Conceptual Graphs model for the attribute and situation fusion. The idea is to let all sensors express their observations in terms of a conceptual observation graph. This approach allows having a high level of flexibility regarding the sources of information that are integrated in the IMSK system. New sensors and technologies can be plugged-in into the system seamlessly, as long as each sensor report can be expressed by a graph defined in the support (see section 4.1).

4.1 Conceptual Graphs for information fusion

The use of the Conceptual Graphsmodel proposed by Sowa in [4] and further developed by Chein and Mugnier in [5] has several advantages. The CG structures are easy to understand by humans and they are a graphical view of a logical formalism. Relying on logics is an advantage for further reasoning purposes. Using conceptual graphs also allows us to take advantage of the theoretical studies that were achieved on this model as well as existing operations and algorithms on graphs in general and conceptual graphs in particular.

The Conceptual Graphs model is essentially composed of a taxonomy called the *support* and the graphs themselves. The support defines the hierarchy of the different types of concepts and relations which are used in the conceptual graphs. These concepts and relations represent the different kinds of things that may exist in the world that we aim at representing and the different kinds of relationships that may hold among these things. The things, or *entities* can be, for instance, the agents of the situations, properties of these agents, actions performed by the agents or abstract entities. A subset of the support representing the entities used in our example is depicted on figure 3. The support used within the situation recognition sub module of the knowledge fusion process of IMSK corresponds to the taxonomical part of the domain ontology defined in 3 and is derived automatically from the OWL description of the ontology.

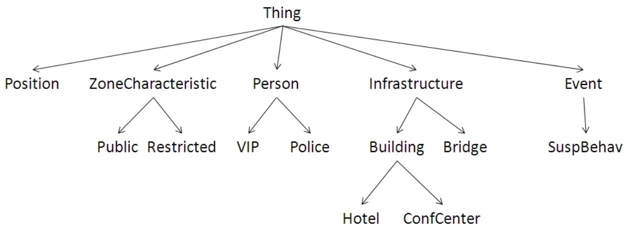

Figure 3: Subset of the ontology for the VIP protection scenario

A conceptual graph is a graph with two kinds of nodes: concept nodes and relation nodes. Figure 4 gives an example of a conceptual graph. The boxes represent concepts and the ovals represent conceptual relations. The graph depicts a situation where a vehicle identified by the number "123ABC" is approaching a bridge that has the characteristic of being a protected area.

The concept nodes represent the entities that exist in the world. A concept label is made up of a concept type and an individual marker. The conceptual type defines the category

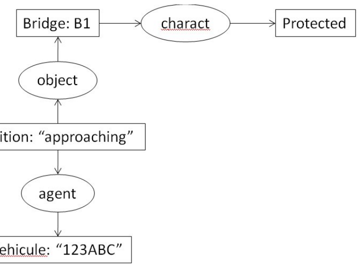

Figure 4: Example of conceptual graph

to which the entity belongs. The individual marker relates a concept to a specific object of the world, or specify the value of the entity. The relation nodes of a conceptual graph are labeled with a conceptual relation type that points out the kind of relationship that link two concepts.

4.2 Information Synthesis

Existing studies such as [6] state that the observed states of the objects should be uniformly reported by the different observers in order to be fused. Two observations of the same object or situation must be described exactly the same way in order to be fused. This hypothesis is two restrictive. Therefore, one must elicit and encode the domain knowledge that is necessary to solve the conflicts between the different observations.

The information synthesis process relies on the use of the maximal join operation on conceptual graphs. The maximal join allows to fuse two compatible subgraphs of two conceptual graphs. One can fuse two graphs G1 and G2 if they share compatible subgraphs. In other words, they must have a common generalization G0 with compatible projection $P_1 : G0 \rightarrow G1$ and $P_2 : G0 \rightarrow G2$ that are compatible. P_1 and P_2 are compatible, if for each concept c of G0:

- $P_1(c)$ and $P_2(c)$ have a common sub-type different from the absurd type $\perp$,
- the referents of $P_1(c)$ and $P_2(c)$ are conform to their most general common sub-type,
- the referents of $P_1(c)$ and $P_2(c)$ are either equals, or one of them is undefined.

The maximal join of G1 and G2 is build by joining the nodes that have an image by the compatible projection.

In order to fuse observations that are not strictly identical, we propose to introduce domain knowledge inside the maximal join operation. This domain knowledge is encoded as *fusion strategies* and is used in order to relax the constraint of strict equality between the values of the concepts nodes of the graphs during the process and choose the value of the fused nodes.

Formally, the fusion strategies are expressed as rules that encompass two functions: a compatibility testing function, and a fusion function.

Definition 4.1. *Let $\mathcal{S}$ be a lattice of conceptual types and l be a set of individual markers. $\mathcal{C}$ is the set of concept nodes defined on $\mathcal{S} \times l$, G_1 and G_2 are two conceptual graphs defined on $\mathcal{S}$ and c_1 and c_2 are concepts defined on $\mathcal{C}$ such that $c_1 \in G_1$ and $c_2 \in G_2$.*

A fusion strategy $\mathrm{strategy_{fusion}}$ *is defined as follows:*

$$strategy_{fusion} = \begin{array}{ll} if & \mathrm{f_{comp}}(c_1, c_2) \\ then & \mathrm{f_{fusion}}(c_1, c_2) \\ else & \{c_1, c_2\} \end{array}$$

where $\mathrm{f_{comp}} : \mathcal{C} \times \mathcal{C} \rightarrow \{true, false\}$ *is a function testing the compatibility of two concept nodes, and* $\mathrm{f_{fusion}} : \mathcal{C} \times \mathcal{C} \rightarrow \mathcal{C}$ *is a fusion function upon the concepts nodes of the graphs.*

To define the compatibility testing function, we rely on the use of two functions that measure the similarity of the two conceptual types, and the similarity of the values of the concept nodes candidate for fusion.

Definition 4.2. *Let $(c_1, c_2) \in \mathcal{C}^2$, with t_1 (respectively t_2), the conceptual type of c_1 (respectively c_2) and v_1 (respectively v_2) the referent of c_1 (respectively c_2).*

The compatibility function $\mathrm{f_{comp}}$ *is then defined as follows:*

$$\mathrm{f_{comp}}(c_1, c_2) = \mathrm{sim_{type}}(t_1, t_2) * \mathrm{sim_{ref}}(v_1, v_2) \geq t$$

Where $t \in [0, 1]$ is a threshold defined by the domain expert.

and where the similarity $\mathrm{sim_{type}} : \mathcal{S}^2 \rightarrow [0, 1]$ *is defined as follows:*
$\forall (t_1, t_2) \in \mathcal{S}^2$,

$$\mathrm{sim_{type}}(t_1, t_2) = \begin{cases} 1 \text{ if } \exists t \in \mathcal{S} \text{ with } t \leq t_1 \text{ and } t \leq t_2 \\ 0 \text{ otherwise.} \end{cases}$$

$\mathrm{sim_{ref}}$ *is defined according to the data type that is used to express the value of the concept. If the value is expressed as a string, one may use a normalized version of the string edit distance, for instance. If the value is expressed as a numerical value, the difference between the two values may be compare to a requested precision threshold.*

5 Situation/Event recognition

The aim of the situation (or event) recognition module is to recognize specific predefined situations such as the detection of explosive in a protected area for instance, from the observations gathered on different sources. The predefined situations are recognized (or detected) thanks to the comparison of patterns of critical situation with actual observations made through the sensors (possibly preprocessed through one of the fusion modules of IMSK) or acquired from open information sources.

5.1 Situation Modeling

The aim of the situation modeling phase is to define the ideal situation the end-user is interested in recognizing from the outside world. This ideal situation is a model (or pattern) of the situation that is to be observed. The objective of the situation recognition submodule will then be to decide whether an instance of the situation model can be found in the observed fused situation. Situation modeling therefore follows the approach recommended by Minsky [7] with his *Frames* and is also similar to the *Case Based Reasoning* approach introduced by Schank and Abelson [8].

To store domain knowledge, and more precisely the models of the situations of interest to a user, we use partially abstract conceptual graphs. Potential interactions between the entities (defined as concepts and relations in the ontology) are represented using conceptual graph structures. The concepts used in these graphs have no referent as they are formed from general knowledge. They depict how the entities of the modeled world generally behave. Generally, no individual marker will be specified, unless a concept represents some general knowledge independent from the observations that can be made (e.g. `[Water] -> (boils_at) -> [Temp = ''100C'']`).

Considering our scenario of protection of VIPs, we defined a model that states that if there is a vehicle approaching a specific protected bridge, and a VIP is on that bridge, the situation is recognized as being critical. This model is depicted by the graph on Figure 5

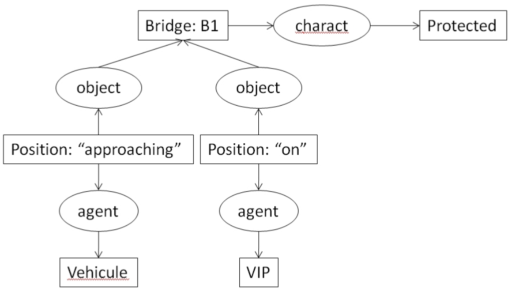

Figure 5: Model of a critical situation

5.2 Situation Recognition

Once the different observations have been combined and fused, a picture of the global situation is available as a graph. The aim then is to decide whether the situations described during the situation modeling phase have been observed or not. We use an approach close to the one presented in [6], which has the same objective.

If predefined situations are only partially observed, the probable existence of non observed elements of the situation may be inferred, based on the use of the situation models. Situation Recognition provides a list of recognized situations. This allows raising alerts that are transmitted to the C2 operator. The recognized situations (or events) are also transmitted to the event correlation module in order to be analyzed with dynamic perspectives.

The process of situation recognition relies on the use of projection search between the situation models expressed as graphs and the fused observation graphs.

Definition 5.1. *An observed situation Obs is an instance of the situation model Mod if the following conditions are fulfilled.*

Let N_{Obs} be the set of nodes of Obs and N_{Mod} be the set of nodes of Mod. There shall exist a graph isomorphism $\mathrm{p} : Mod \rightarrow$ *Obs such that:*

- $\forall n_{Obs} \in N_{Obs}$ *such that* $\mathrm{p}(n_{Obs}) = n_{Mod}$ *with* $n_{Mod} \in N_{Mod}$*;*
- *if n_{Obs} is a concept node, its label is defined by the type t_{Obs} and the value v_{Obs}. n_{Mod} is defined by the type t_{Mod} and the value v_{Mod} and we have t_{Obs} is either equal to or a subtype of t_{Mod} and v_{Obs} is either equal to v_{Mod} or v_{Mod} is undefined.*
- *if n_{Obs} is a relation node, its type t_{Obs} is equal to the type t_{Mod} of n_{Mod}.*

An observed situation is said to be a full instance of the situation model if it entirely fills the situation model (i.e. if all the nodes of the model have an image through the projection defined above). A level of recognition is associated to each recognized situation. It is a real number included into the [0, 1] interval. The level of recognition is equal to 0 when the observed situation is not projected at all in the model. The level of recognition is equal to 1 when the observation is a full instance of the situation model.

The observation depicted on Figure 4 partially fills the model depicted on Figure 5. If we consider an other source of information, for example, the schedule of the summit, we may get the observation depicted on Figure 6. After fusing the two observations (Figures 4 and 6), using the approach described in section 4 we obtain a fused observation graph that fully fills the critical situation model.

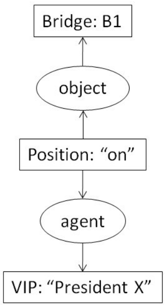

Figure 6: Information provided by the summit schedule

When a situation, or a particular occurrence of an event, has been recognized in the observations, its description is sent to the event correlation module. The aim of the event correlation module is to process the numerous recognized situations together with pieces of information and observations coming from other sources and fusion modules and detect specific configurations of events that must be reported to the C2 operators.

6 Event correlation

Let us now consider that the two previous observations arrive to the system with two different (incompatible) dates. Due to the different dates, the fusion module will not fuse these observations. However, the reason for the difference between the two dates is that there is a delay in the official schedule of the summit. This delay information is accessible by the knowledge fusion sub system, but can not be combined with the other observations at the attribute and situation fusion stages.

The vehicle is indeed approaching the bridge at the same time as the VIP is crossing it. One has to detect the situation. This is the job of the event correlation module, which correlates different observed events, using time and space information. Different observed events that cannot be fused can trigger correlation rules and produce alarms.

The Event Correlation sub-system of IMSK recognizes two types of correlations of events and/or facts registered in the knowledge base of the knowledge fusion sub-system:

- anomalies requiring the attention of the C2 operator, i.e. the conditions characterizing an "abnormal" correlation of events are explicitly stated,
- unacceptable or unexpected event correlations requiring the intervention from the C2 operator, i.e. the conditions for "normal" correlation of events are specified and all deviations are considered suspicious.

Both types of correlations are represented as rule sets, which have to be defined and configured before applying them in an operative IMSK system. A rule set specifying a specific event correlation will in the following be called correlation model. For instance, concerning VIP protection, different events and facts, like vehicle movement, location of the VIP and discovered threats, have to be considered as correlated. A rule set describing this event correlation will be defined as a correlation model, expressed in a declarative language and allowing reasoning in an appropriate logic language, e.g. as (subject, predicate, object) triples.

All correlation models have to be compliant with the domain model. The subjects and objects used in the rule sets of a correlation model are concepts from the domain model and the predicates of the rule sets are relations or properties in the domain model.

The event correlation sub-system exploits events registered by the data fusion or information fusion sub-system and leads to notifications, which are sent to the C2 system together with information that supports decision making of the C2 operator.

Unexpected event correlations and anomalies can be defined based on the domain model. An *unexpected event correlation* can be described as follows: Let $SE := \{C^{SE}, rel^{SE}, A^{SE}\}$ be the rule set describing an unexpected event correlation, consisting of

- a set of concepts C^{SE} being a subset of the concepts in the domain model
- a set of relations rel^{SE} being a subset of the relations in the domain model
- set of axioms A^{SE} over the concept set C^{SE} and the relation set. A set of facts created in input data interpretation based on observation is an unexpected event correlation if all axioms in A^{SE} evaluate true.

Furthermore, an *anomaly* is defined as follows:
Let A^A be a subset of the axioms of the domain model and each axiom $a_i \in A^A$ describe an anomaly to be detected.

Once single events are observed, the sequences (in time and space) of these events are evaluated to detect abnormal dynamic situations.

7 Conclusion and Future work

In the context of the IMSK project and based on requirements from scenarios analyzed in this project, this paper addresses a knowledge fusion application in the field of civil security. The main focus of the work is on the architecture of the knowledge fusion sub-system which integrates different fusion aspects based on a common domain model and embedded into a distributed and mobile infrastructure. The paper specifies the integrated way of using attribute fusion, situation recognition and event correlation in the IMSK knowledge fusion sub-system.

The main limitation of the paper is that it stays on the level of specifying domain model, architecture of the fusion sub-system and the different parts of the fusion approach. The implementation work within IMSK is scheduled for the second half of 2010 and the beginning of 2011. Thus, implementation of the sub-system and integration in the IMSK platform will be the major line of future work. Evaluation in real-world scenarios and enhancement of the knowledge fusion approach based on lessons learned are planned after the implementation.

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