SaR Resource Management based on Description Logics

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Abstract The management of resources is a great challenge for commanders in Search and Rescue operations and has a strong impact on all areas of operation control, as command-and-communication structure, geo-referenced information, and operational tasks are inter-connected with complex relations. During an operation these are subject to dynamic changes. For an efficient operation control commanders need access to up-to-date information in their mobile working environment. This paper presents a new approach to manage resources and their relations in an operation. It is based on ontologies to build a model of an operation and Description Logic reasoning to provide enhanced decision support.

1 Introduction

Search and Rescue (SaR) operations are characterised by well-established structures concerning command, control and communications, spanning the whole range of units and tasks involved in the operation. For a more descriptive scenario this paper focuses on fire brigade operations. As a result of national regulations a wide range of personnel is included in such operations. German fire brigades (professional and volunteer) and emergency medical service are organised on urban level and are under the same supervision and control. Rescue service and civil protection are overtaken by national or private organisations.

Under these circumstances the *Resource Management* in terms of control and organisation of heterogeneous personnel, vehicles and equipment within large scale operations means a great challenge. Resources must be managed by building formations, setting geo-references and assigning tasks with respect to qualification. Thus complex relations are created and dynamically re-arranged, e.g., depending on the size of the incident or its progress. Thereby information is implied which can enhance operation management and decision support.

This paper is organised as follows: It first introduces the structure of SaR operations of the German Fire Brigades and its modelling with Description Logics, a logic formalism for representing ontological Knowledge Bases. Subsequently, a logical and computational infrastructure to utilise Description Logic reasoning for operation resource management is presented. Based on the impact of resource management for SaR operations the application in the dynamic environment of operators and commanders is presented. The paper concludes with a discussion of the proposed system's advantages and shortcomings and a mention of possible improvements and extensions.

The work described here is part of the IST project *SHARE: Mobile Support for Rescue Forces, Integrating Multiple Modes of Interaction.* It is intended to offer an information and communication system to support emergency teams during large-scale rescue operations and disaster management.[3]

2 Search and Rescue Operations

The backbone of an operation is the communication between the forces and adequate information to support decision-making processes. Operation control can be cut down to the management of actions and the acting units, vehicles and persons. Therefore adequate techniques have to be utilised [1]. Nowadays radio messages and paper-based message exchange have obvious problems in information loss, time efficiency and documentation possibilities. Sets of maps and plans which are in most places still used in paper versions constrain the usage and information supply. Magnetic boards are used in order to place tactical symbols and draw additional notes and sketches. This established method often causes problems concerning clarity. For this manifold set of tools it is obvious that there is no chance to build up on a common data or knowledge base. Information is available in incompatible physical formats and spread over the different command cars and units. Although some stand alone ICT solutions exist for map application, messaging and documentation this problem is still not solved.

Explorations in the field of SaR show that there is a defined and very strong relation between communication and information [2]: communication is needed on the one hand by speech and forms, on the other hand by exchange of operational data. This leads to the needs in information support which can be divided to static data and dynamic information. Especially communication to provide this dynamic data to specific operating units is a foundation for efficient operation control. Thereby resources are one of the most important objectives, either referenced directly or indirectly. Operating officers are on the one hand part of the resources, on the other hand prospective system users. Thus their command levels have to be taken into account (see figure 1). In most cases a differentiation of three command levels is defined. The most common terms for the three command levels are *A–B–C Level* or *Gold–Silver–Bronze*, corresponding to the strategic, tactical, and operational level, respectively. The complex relations of resources to communication channels, geographical sectioning and task assignment build a high information potential which can hardly be utilised by currently used media.

[3] Please see `http://www.ist-share.org/` for more details about the SHARE project.

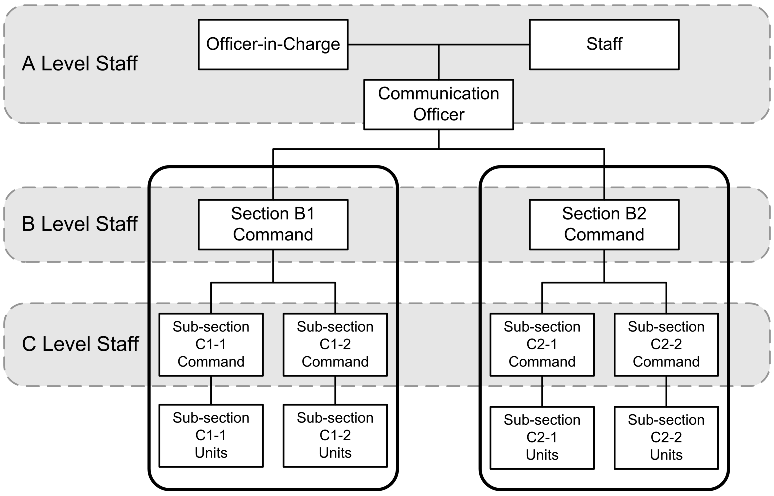

Figure 1. The command-and-communication structure of a SaR operation

3 Logical and Computational Infrastructure

The resource management system described here relies on Semantic Web technologies in order to model the operation, derive inferences from the model, and provide for the interaction between the (inferred) model and the resource management application of the end-user.

The operation is modelled as an *ontology*, an abstract representation often used in the areas of Knowledge Representation, Artificial Intelligence and the Semantic Web as a way of structuring and representing knowledge. *Description Logic* reasoners are used to deduce knowledge that is implicit in the model; ontologies and Description Logics are two technologies that are developed in parallel. They are closely inter-dependent as the reasoner must be able to act upon the structures provided by the representation formalism and the latter must be able to represent the structures supported by the former.

Finally, the explicit model and the implicit (derived) knowledge is made available through a data service that exposes a web-service interface to the knowledge base. End-user applications access the web services over the SHARE system's mobile network infrastructure.

3.1 Ontology Representation

The elementary pieces of information in the ontology—corresponding to the individuals of the domain of discourse—are called *instances*. Instances are organised in a conceptual hierarchy (a taxonomy), where each *concept* (sometimes also called *class* or *frame*) groups together a set of conceptually similar instances.

Concepts are defined by the *properties* that their members must carry to be admitted as members. Such membership rules might be necessary but not sufficient to guarantee admittance, or they might be necessary and sufficient. Concepts with membership rules of the latter kind are called *defined concepts:* in these concepts, instances that are not explicitly included might be admitted through inference based on the concept's definition. Concepts, on the other hand, where explicit inclusion is the only ticket to admission are called *base concepts.*

The concept hierarchy is a *subsumption hierarchy*, where super-concepts include all instances of their sub-concepts and possibly some more. It is also an *inheritance hierarchy* where instances of sub-concepts have all the properties of their super-concepts, and possibly some more. Properties are either *relations* between two instances or *data properties* (or *attributes*) that link a single instance with a concrete value, like a number or a string. Relations can also be placed in a subsumption (inclusion) hierarchy.

It is a strong desideratum that ontology structure and instances be represented in a formalism that is both machine and human-readable. The most recent development in ontology representation is the Web Ontology Language (OWL) [3], defined within the Resource Description Framework (RDF) [4]. In short, RDF represents knowledge as triples which combine a pair of objects with a predicate. OWL is a series of increasingly expressive RDF languages: OWL Lite, OWL DL, and OWL Full. OWL Lite and OWL DL have the important property of being compatible with Description Logics (DL), a decidable fragment of First-Order Logic, which facilitates reasoning over the ontologies represented in either of these two formalisms.

The SHARE system uses OWL DL in order to ensure compatibility with DL reasoning engines. OWL Lite representation would have been advantageous from a computational point of view, but not applicable to SHARE, as it would omit important aspects of the operational model.

3.2 Description Logics

Description Logics (DL) are a family of formal logic formalisms for representing knowledge. The most fundamental common characteristic of all DLs is that they are dyadic first-order logics, i.e., they are within the fragment of first-order predicate logic expressible by up to two variables per clause. This very restrictive limitation makes DLs compatible with the RDF framework, which represents knowledge as predicate–object1–object2 triples. Furthermore, it has the important computational property of being decidable, where full first-order predicate logic is not.

A DL knowledge base typically comprises two components: the TBox and the ABox. The *TBox* contains the terminology of the domain in the form of declarations that describe general properties of concepts. The basic reasoning service of the TBox is subsumption, which is used to (a) check that a concept does not necessarily denote the empty concept (satisfiability) and (b) classify new concept expressions in the proper place in a taxonomic hierarchy of concepts.

The *ABbox* contains factual knowledge regarding the particular problem at hand and is specific to the individuals of the domain of discourse. The basic reasoning service of an ABox is instance checking, which decides whether a given individual is an instance of a specified concept. Instance checking is the underlying operator under a number of facilities, like *consistency checking* (i.e., verifying whether every concept in the knowledge base admits at least one individual) and *realisation* (i.e., identifying the most specific concept an individual is an instance of, based on the individual's properties).

3.3 SHARE Ontology Data Service

SHARE-ODS, the SHARE Ontology Data Service, is a comprehensive data and knowledge service for the SHARE system [5]. Explicit data about an operation and domain knowledge is represented in an OWL ontology as instances and axioms, respectively.

The model of the operation is organised as a number of sub-ontologies. Most central to the work described here is the SaR ontology, which holds all knowledge pertinent to the unit, command, and communication structure of the operation, personnel assignment, unit deployment, assignment of tasks and geographical areas of responsibility to units, etc. In addition to the SaR ontology there is a Multimedia ontology (communication objects exchanged during the operation), and the auxiliary Time and Space sub-ontologies that represent spatio-temporal references and actual geographical features (buildings, streets, etc) present at the theatre of the operation. All sub-ontologies are tightly integrated in a comprehensive model of the operation and extensively cross-linked.

Fire brigade rules and practices with respect to operational structure are encoded as ontological axioms in the SaR ontology. A particular operation's compliance is checked by a Description Logic reasoner. Access to the ontology and the reasoner's conclusions is provided though Web Services that use SOAP messaging [6] to export functionality to populate, update, and query the SHARE knowledge base.

4 Dynamic SaR Resources

The investigation of SaR resource management has to be based on the operational workflows. An emergency call defines parameters like the incident type, time and geographical information and affected human beings. Based on that an initial set of resources gets alarmed. Therefore two sources are utilised: Information about available units and a set of general rules, laws and regulations. During an operation the incident can change, units must be re-organised, personnel substituted after a certain duration and special forces deployed. These exemplary reasons require intelligent operation control support at the fire site. According to [7] the responsible instance is the Officer-in-Charge acting on-site in his mobile and dynamic environment.

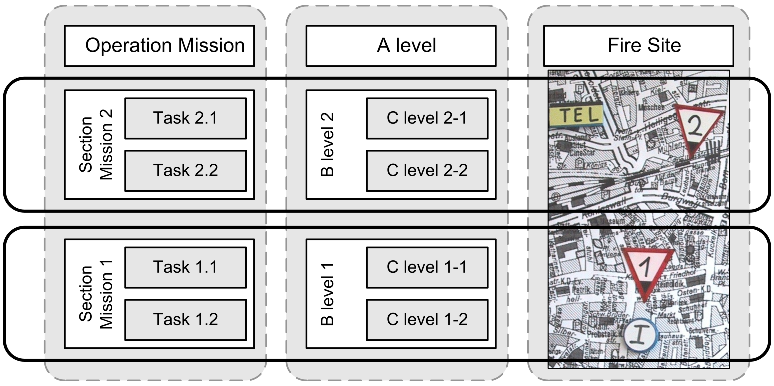

Figure 2. Dependency between resources (e.g., B level staff), geographical sections and tasks

4.1 Operational impact of SaR resource management

For an efficient execution of firefighting tasks a *divide & conquer* approach is used: The fire site is divided into sections and sub-sections for functional or only geographical reasons. The initial command structure is built based on functional requirements. Thus this structure implies functional sectioning with regard to the incident and concerned danger averting measures, the available resources and regulations resp. laws. These functional sections have to be mapped to geographic references. Therefore input is given by characteristics of the incident, the scene (terrain, buildings, objects, dangerous goods, etc.) and the resources which provide special features. Figure 2 demonstrates the challenging relations between resources, tasks and geo-sectioning. They must be kept up to date during the highly dynamic changes within an operation.

These facts sketch a rough background for the requirements which they imply for a mobile ICT environment. Following a user-centred approach every officer must be provided a structural overview of the scene, mainly of the part of the hierarchy he is responsible for. Corresponding to the command levels a *Level Of Detail* of contents is reasonable. e.g., an operational commander has to be aware of very much details about his vehicles and firefighters while tactical or strategic commanders are interested in more general information. One parameter which only seems to be very simple is the manpower available at the fire site: currently it is very difficult to collect all needed figures using radio communication. Even more complex is the need to keep these figures up to date, but a bottom-up information collection and aggregation scheme distributes the necessary effort.

While the operation control centres in the back-end dispose resources the on-site operation control has to manage the units available on-site. Every officer is responsible for his sub-ordinated units. Thus rights and restrictions on rights have to be set accordingly for the functionality. The user interface must follow such requirements. Management of resources in this context means to move formations or vehicles within the structure, take elements out of operation and deploy new ones. In many professional fire departments alarm levels are predefined: They are increased when the incident becomes more complicated and decreased vice versa. Based on an alarm level the general structure of resources can be inferred. Therefore logical restrictions on types of resources and their relationships must be defined and proved when a change arises.

4.2 SHARE-ODS and Resource Management

The SaR sub-ontology models the objects that are related to the structure of the operation: the resources engaged in the operation, the command and communications structure, and the task and area of responsibility of each formation. SaR concepts include formation levels (A, B, or C level) and types (professional or volunteer fire-brigade, rescue service), operational roles and actual personnel, vehicle and equipment types, etc. Formations are also linked to the geographical area (section or subsection of the operation theatre) that they are responsible for, and the task they are expected to carry out within this area.

Formations and their units are linked together in a so called partology, and are also connected to operational roles they require (e.g. commander, dispatcher, etc) which, in their turn, are connected to the actual personnel members that fulfil each role. The knowledge base is explicitly populated with this information as the operation proceeds and units arrive to the theatre and are deployed.

Several characteristics of the operation's structure are inferred from this explicit information and the definitions in the ontology model, e.g., fire-brigade formations are defined as professional or auxiliary (volunteer), depending on the units and officers they are made up from; they are also defined as *full* or *base* formations depending on the number and type of sub-formations they subsume.

SaR operation regulations and practice have specifications regarding admissible operation structures, depending on the *alarm level*, i.e., the extend of the emergency. These specifications are formulated in terms of maximum and minimum numbers of full and base formations from each service (fire brigade or rescue service) that must be involved in an operation at each given alarm level. Generally speaking, as alarm levels rise operation structure gets 'fuller' and more populous.

The SHARE ontology models these specifications as defined concepts corresponding to well-structured formations of all three levels, for all alarm levels possible. For example, there is the concept of the well-structured C-Level Formation at alarm level 1, the concept of the well-structured C-Level Formation at alarm level 2, and so on, until all formation level and alarm level combinations are exhausted. SHARE-ODS uses instance checking to decide if the structure of an operation matches the specifications of a given alarm level, and also pinpoint the part of the operation structure that should be modified in case of a mismatch.

The Resource Management functionality is particularly useful when upgrading or downgrading the alarm level of an operation. Such an upgrade or downgrade can, for larger operations, require a significant number of unit deployment

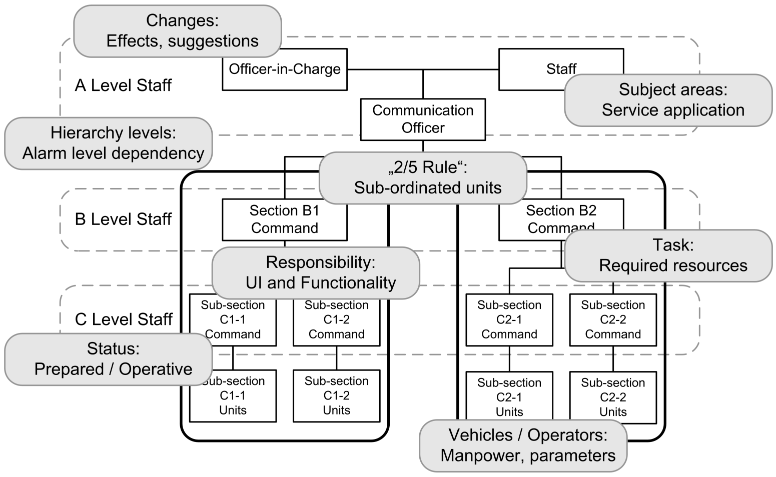

Figure 3. Basic restrictions for the command and communication structure

or disengagement actions to be performed. Thus such a tool can provide substantial help to the operation's command staff.

4.3 Application of Interactive Resource Management

The requirements of commanders are implemented in the Interactive Resource Management (IRM) application which is embedded to the SHARE client. This client is designed following a thin client approach as it should be applied to mobile devices wearable in firefighting operations. The evaluation phase of the SHARE project brought out that Tablet PCs are the best solution for all command levels working either tactical or operational in the field. This is possible as the administrative parts of operational command are overtaken by assistents located inside command cars. For crucial input commanders themselves can handle a Tablet PC in short distance to the car. Plans for the usage of Handheld PCs were not favoured mainly because of their limited screen size. The GUI provides three different views to resource information: a) *view* resource information, b) *manage* resources at the fire site and c) *supervise* the connection between operation control centers in the backend and the operation scene.

The different use cases can be explained by the following example. Figure 3 highlights the relations and hierarchy elements which are affected by the described restrictions. A command structure with three hierarchy levels is presumed, called alarm level three. Staff members control certain subject areas, one is responsible for the management of resources. Commanders and staff communicate their status via analogue radio. Regarding this and processing information from the operation control center they supervise the operative and assembled units at the fire site. In this scenario he registers a pre-defined C level arriving at the assembly area consisting of a command car, three fire engines and concerned personnel. Thereby this unit gets visible to the IRM as a prepared resource available to be deployed. Commanders have access to their subordinated resources as well as all prepared resources. Because of a growing fire incident a B level officer orders the newly registered C level unit. This simple *drag & drop* action causes a command to the accessed unit, a preliminary change to the command and communication structure and the generation of a new operational rôle. With the arrival at the operation ground the C level officer overtakes this rôle by login and thereby finalizes the structural change. Corresponding log entries are stored. The officer-in-charge gets an information about this update. As the change affected the logical restrictions for alarm level 3 an exception is presented about a) the changed elements, b) the active operator and c) the suggestion to increase the alarm level. To decide on this the officer-in-charge retrieves information from the general view, e.g. about the type of vehicles that were added and the calculated new manpower. By his manage options he increases the alarm level. Additional upcoming inconsistencies regarding the new alarm level are highlighted.

The illustrative example presented some important aspect: The functionality behind the interface is designed user dependent whilst users are represented by the rôle they overtake. These rôles are command level related, except the supervisor rôle. The same applies for the view to resources. While officers want to view the overall structure, they only have to manage their subordinated formations for vehicles. The view to resources comprises the hierarchical structure, communication channels, defining characteristics and logistics information. Management of resources means the deployment, disengagement or structural movement of resources. This implies changes in the relations between resources defined in the SaR ontology. Every change is passed to the reasoning engine to check for inconsistencies. When existing a corresponding exception is thrown by the service. A package of special exception classes are modelled using inheritance to provide feedback as specific as possible. The interpretation of such messages informs about errors and suggest alternatives.

5 Conclusions and Future Work

We propose an ontological model that unifies SaR operation modelling with semantic annotation of documents, to offer an integrated model for an operation and all documents pertaining to it. Furthermore, we are putting together a set of tools for using the ontology at an actual SaR operation. These tools include the SHARE Ontology Data Service for updating and accessing the semantic data and the reasoning facilities that complete the original facts with inferred knowledge.

We are investigating various directions in which to extend the system. A major issue with SaR operations is data reliability: as an operation unfolds, the ontology gets populated by various sources, some reliable (e.g. GPS) and some not (e.g. information extraction modules). Faulty data can be caught (and, possibly, corrected) when creating logical inconsistencies, which can be resolved in favour of the more reliable source. In cases where multiple sources corroborate towards accepting or rejecting multiple pieces of information, the problem of deciding which to accept as most reliable becomes non-trivial. This problem has been approached in various domains, but not in the domain of responsibility distribution among multiple information extraction sources.

Another interesting direction we plan to pursue is temporal representation and reasoning for the purposes of *planning* (before and during an operation) and *evaluation* of past operations. At this stage, the SHARE ontology models only the current situation; a temporal model an reasoning engine will allow to track an operation's progress through time. Such an ontology will include a model of the task assigned to each formation, and reasoning over it will identify parts of the operation that are ahead of schedule or lagging behind. Such a model converges to a powerful decision support tool that not only checks the current operational status, but also offers helpful suggestions about resource re-allocation, by identifying resources that are being under-used and sections that are under-resourced.

Finally, the system currently points out to the user aspects of the operation that are not conforming to some rule, without offering any indication of the gravity of the rule that is being broken. At a future system we plan to explore the possiblity of using weighted rules, so that suggestions to the user are accompanied by an 'importance' comment or colour-code. The weighted model can be computed by collecting situations of officers ignoring the official guidelines. Such situations will be compilied into a dataset, to be used to learn models of such exceptional decisions and the operational cirmustances that trigger them.

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