Towards Contextualized Information Delivery:
A Rule-based Architecture for the Domain of Mobile Police Work

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A Rule-based Architecture for the Domain of Mobile Police Work

PROEFSCHRIFT

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Beibei Hu
Delft, October 2011.

Contents

Part I

Introduction

Chapter 1

Introduction

In the domain of mobile police work, the amount of information that police officers come into contact with in the course of their work is astounding (Luen and Al-Hawamdeh, 2001). When carrying out their tasks, they need to have up-to-date information contextualized to their current situation in order to support their decision making. Evaluations of past incidents have revealed that wrong decisions by police officers can often be traced back to the lack of critical information (ACIR, 2005). An example that drew a lot of media attention was an incident that happened in Amstelveen, the Netherlands, in July 2008. In that incident a police officer was shot dead by the driver of a car when she was approaching the car to question the driver for his erratic driving[1]. The fatal problem proved to be that the officer was not notified beforehand that the suspect was potentially holding a weapon and had been involved in another incident earlier that evening. Moreover, the suspect had a record of violent crimes. This example suggests that mobile police officers can work better and safer if they have technical support in the form of information systems which can proactively deliver relevant information contextualized to their current situation and needs.

In general, the typical mobile users of today need access to information anytime and anywhere in order to assist the activities they are engaged in. The advancement in web service technologies has significantly increased the ability to provide the right service or information to the right user. An increasing number of mobile users demand adaptive services tailored to their specific requirements in a particular situation. For example, tourists expect web services to be aware of their current environment, i.e. the location, the weather and landscape attractions. Another example of awareness would be related to devices when a project leader might want important E-mails, such as a notification of a change in a meeting schedule, to be forwarded to a voice mail on her smart phone when she is in transit to attend the meeting. In contrast to the traditional work environments in which workers are involved in standard office work, the situations in which mobile workers perform their tasks are characterized by various types of context. This feature requires the designers of a system serving those mobile users to understand which context dimensions might influence the users' information needs; thus, developers must find solutions that enable applications to adapt their behaviour to the current context without consuming too much of users' attentions (Dey, 2001). This context-awareness is a central theme in our research work.

[1]http://www.masscops.com/f38/dutch-police-officer-killed-traffic-stop-57836/

In order to support mobile users in performing their tasks, there is a lot of research on the provision of relevant services or information by taking into account the dynamic environmental context (Cheverst et al., 2000; Gu et al., 2005; Raento et al., 2005). In the area of human-computer interaction, the context factors also include current user state, inferences on user behavior and long-term user properties (such as knowledge and preferences in interaction style) that are relevant to the interaction between a user and a system (Streefkerk et al., 2006). Context appears as a fundamental key to enable systems to determine the relevant information from large amounts of available information (Vieira, 2010). In spite of the different definitions of context, one of the most acknowledged definitions is provided by (Dey and Abowd, 1999), where context is defined as "*any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves*." That reference also points out four primary context types as being more important than others, i.e. location (*where*), identity (*who*), activity (*what*) and time (*when*).

Context-awareness, which is a key technology in ubiquitous, handheld and wearable computing, is considered as the ability of a device or program to sense, react or adapt to its environment of use (Pascoe et al., 1999). Applications which can automatically provide relevant information by taking advantage of the context variables and decide its relevance depending on users' tasks, are defined as *context-aware systems* (Dey, 2001). Through using the above mentioned four primary context types, the designers can encode certain actions in the context-aware applications and thus enable the applications to determine what information users might need. For example, when a user is driving to a destination (*activity* and *location*), the location-aware guide system might be configured to accordingly deliver the navigation information (*action*). Moreover, context-aware applications look at the identity, location, time and activity of entities and use this information to determine why the situation is occurring (Dey and Abowd, 2000). In order to enhance user experience, systems for context-aware mobile support also take into account human factors, such as attention, workload and individual differences (Streefkerk et al., 2007).

In the early stage, most context-aware applications focused on providing information according to the user's current location, such as the Active Badge Location system (Want et al., 1992) and many tourist guides (Abowd et al., 1997; Davies et al., 2001; Dey et al., 1999; Pearce, 1984). More recently, there have been many attempts to utilize broader dimensions of context beyond mere spatio-temporal context. In particular, we have seen attempts to go beyond capturing the physical context (low-level context) that can be measured by hardware sensors (Prekop and Burnett, 2003), such as location, temperature, speed, light, etc; likewise, more and more approaches are moving towards making use of logical context (high-level context), recognizing the user's activities, goal, task, expertise and cognitive workload (Balabanović and Shoham, 1997; Neerincx and Streefkerk, 2003; Schmidt et al., 1999). Such context-aware applications, which are able to provide relevant information to facilitate task accomplishment, range from personal assistance in daily activities to critical decision making. Typical examples for supporting daily activities include a conference assistant (Dey et al., 1999), a smart phone (Schmidt et al., 1999), ubiquitous learning (Economides, 2009) and a context-aware system for the operating room (Agarwal et al., 2007). More importantly, context-aware services have a positive impact on society and economy. For instance, contextual advertising not only brings benefits to the online advertising industry by providing more revenue, but it also improves the user experience (Broder et al., 2007). An intelligent cost estimator offers real-time decision support, in an uncertain e-market environment (Islam, 2007; Yu and Lai, 2003), and a prototype of BeAware! implemented in the domain of road traffic management enables human operators to achieve situation awareness and thus brings the prevention of critical situations (Baumgartner et al., 2010).

As above mentioned, context-awareness has proved to be fruitful in different domains. However, the development of context-aware systems is a non-trivial task and involves many challenges. Developers need to deal with the following issues:

- *How to acquire, integrate and exploit context information from multiple different information sources?* Context-aware systems should be able to capture and integrate context from sensors and other information sources. Moreover, logical/internal context (e.g. activity) should be derived from physical/external context (e.g. location) and further utilize these derived context to characterize the situation of entities.

- *How to reflect the changing information needs of mobile users without explicit user intervention?* The challenge in designing context-aware systems lies in how to detect a change of context that might influence the user's information needs and when and how to provide services tailored to these needs. For instance, a system should be aware of the potential change in demands of a user when a new task emerges without requiring the user to explicitly express her information needs relevant to this new task. In addition, this system should help manage interruptions while presenting tailored information and focus the user's attention appropriately (McFarlane and Latorella, 2002).

- *How to provide a reusable and extensible architecture for designing context-aware systems?* To actually simplify the development of systems that are capable of dealing with various types of context in different situations, a general and reusable architecture is needed for designing context-aware systems (Baldauf et al., 2007; Joshua et al., 2001).

- *How to evaluate the properties of context-aware systems?* Due to the unique characteristics of context-aware systems such as adaptability and proactiveness and so on, technologies for evaluating information systems needs to reflect and measure these characteristics (Hong et al., 2009b). Thus, in evaluating context-aware systems, the challenge lies in which methods and criteria to combine and how to adjust them to application domains (Streefkerk, 2011).

Specifically, to consider the challenge on the design of context-aware systems in police domain, let us turn back to the concrete incident involving a police woman who was shot due to a lack of timely key information. From that example, we can identify the contextual information needs that police officers have. The following specific requirements pose a great challenge on the development of context-aware systems for mobile police work:

- Police officers can be involved in a routine situation like doing patrol or traffic duty, or be in an urgent situation like responding to a fire. A routine situation can at any given time evolve into an urgent one.

- The tasks that police officers perform are determined by the external events they are dealing with, thus their information needs are largely driven by the targeted events or objects. As indicated in that specific incident, the fact that a driver was in possession of a weapon and had a criminal record could have helped that police woman to make the correct decision before approaching the driver.

- Police officers in particular need to be aware of information related to their personal safety when they are in a contextual situation. Also, they need team collaboration support to coordinate actions between distributed team members (Streefkerk et al., 2008a).

Aiming at tackling the above challenges, there exists a rich body of research efforts on context-awareness in various domains, ranging from traffic routing (Cugola and Migliavacca, 2009), virtual tour guides (Long et al., 1996), personalized online newspaper recommendation (Jancsary et al., 2011), healthcare assistance to elderly people (Bottazzi et al., 2006), and also location-based notification for police officers (Streefkerk et al., 2008b). However, our literature review guided us to recognize the following open issues that have not yet been addressed:

First, most of the existing applications are tightly connected to specific domains; only a few approaches offer generic frameworks supported by reusable components that can be applied into different domains (David and Ledoux, 2005; Pascoe et al., 1999; Satyanarayanan, 2001).

Second, despite the fact that most researchers refer to the importance of using various contexts, the primary context information used today is the users' location and the objects within a particular place, that is, they are location/place-based applications (Nguyen et al., 2011). The logical context, such as the user's activity and intended gestures (Hofstra et al., 2008), should also be incorporated in applications to provide relevant services. However, very rarely in research work we see that a user's context considers both the location and the type of activity that the user is involved in.

Thirdly, most of the context-aware systems have been designed to support traditional office work, but few of them consider specific requirements of emergency responders involved in critical situations. Moreover, by reviewing those research efforts on supporting field work practices of emergency responders, we observed that none of them focuses on the computation of the relevance of information given the context. For example, the Siren system has been developed to support tacit communication between firefighters (Jiang et al., 2004), but it has a limitation in that the system just sends five types of alert messages in order to notify whether a firefighter as well as other colleagues are in or next to a dangerous place. The CrashHelp prototype for enhancing emergency medical response has been designed to display aggregate incident information on a GIS interface (Schooley et al., 2010). Nevertheless, it concentrates on incident visualization rather than the provision of relevant information in a given situation. Research is being done into addressing issues of intelligent user interface, such as presenting information for police officers based on models of mobile use context, task and individual characteristics (Streefkerk et al., 2006); and a new type of hardware called "tangible table" for sharing information and decision-making during emergency responses (Hofstra et al., 2008). In addition, context-aware notification, which is able to balance awareness of new information with interruption of an ongoing task, plays an important role in police surveillance (Bailey and Iqbal, 2008; Horvitz et al., 2003; Parasuraman et al., 2008; Streefkerk, 2011). A context-aware mobile support system proposed in (Streefkerk, 2011) represents this trend. This system aims to present messages in the appropriate notification style by taking into account operational demands and human factors. Thus, it focuses on mobile information exchange and team collaboration.

Lastly, it is unclear how evaluation methods and criteria optimized for desktop computing translate to mobile professional environments (Kjeldskov and Graham, 2003; Streefkerk, 2011). To our knowledge there is no evaluation method for quantitatively measuring the properties of context-aware applications in the domain of emergency response.

1.1 Objectives

We have been involved in the MOSAIC project (Multi-Officer System of Agents for Informed Crisis Control)[2] at DECIS lab in cooperation with vtsPN[3] (voorziening tot samenwerking Politie Nederland), the organization which provides the overall Dutch law enforcement and security chain with ICT support. The MOSAIC project aims to enhance situation awareness for emergency responders (i.e. police officers, firefighters and ambulance crews) (de Lignie et al., 2008). In the context of MOSAIC, police officers involved in mobile police work (simply called police officers) are considered as end-users in our research.

Our research focuses on offering a generic architecture for the delivery of relevant information in a context-driven fashion (Hu, 2009). The architecture should be able to (1) model the dynamic aspects of a mobile user's situation (e.g. the activities and the events); (2) predict the relevant information that could assist mobile users to take decisions during their specific activities; and (3) support the adaptability of the applications for delivering information relevant to the contextual situations of mobile users.

With the purpose of demonstrating the applicability of our architecture, the specific goal of our research is to develop a rule-based system which can assess the relevance of information items by taking into account the contextual situations of police officers. To cater for the requirements of end-users, our system should (1) effectively select information relevant to a given context; (2) have generic configurability in the sense that it is able to cover different scenarios; and (3) be easily adapted to different scenarios with a modest effort.

Our main objective of designing a generic architecture for contextualized information delivery has been split into sub-objectives:

1. To understand the information needs of end-users who are involved in dynamic and critical situations.

2. To derive the requirements guiding the design of an architecture for contextualized information delivery.

3. To design an architecture which allows the applications adapt their behavior to the specific needs of mobile users.

[2]http://www.icis.decis.nl/index.php/lang-nl/projects/id-and-valorization/187-mosaic
[3]www.politie.nl/vtspn/

4. To model activities and other dynamic aspects of a situation of mobile users engaging in handling certain events.
5. To develop a rule-based system which can assess the relevance of information items by taking into account the contextual situations of end-users.
6. To evaluate the effectiveness and the generic configurability and also the adaptability of the system which is developed for the domain of mobile police work.

1.2 Research Questions

Our efforts focus on investigating the following concrete research questions:

- **Q1. What are specific information needs of police officers in the context of dealing with small-scale events?**

  We consider police officers engaged in mobile police work as our end-users in the context of the MOSAIC project. A prerequisite for offering technology support for police officers is to have a good understanding of their information needs.

- **Q2. What are the requirements for a generic architecture for the delivery of contextualized information to mobile users?**

  While our end-users are police officers, the architecture we aim to design is by no means limited to this domain and target users. It is necessary to derive the requirements for the design of a reusable and also extensible architecture.

- **Q3. How can an architecture be designed to support delivery of contextualized information to mobile users?**

  Following the requirements, an architecture should be designed which supports the applications for delivering contextualized information for mobile users who are handling the targeted event in a changing situation.

- **Q4. How can we model contextual situations of mobile users engaged in tasks aimed at certain events?**

  One fundamental issue in providing service or information tailored to the needs of mobile users in specific contexts is establishing a context model. It is important to capture the relevant context dimensions and represent the semantics of the context information. In particular, we need an explicit model for situations in which police officers are involved by taking into account their specific requirements.

- **Q5. How can a system for contextualized relevance assessment be implemented to show the feasibility of the architecture?**

  To show the applicability of the architecture, we need to apply it to a specific domain (e.g. the domain of mobile police work) and thus develop a system which can meet the requirements of end-users. Given that the situations of mobile users are changing, we should define a mechanism allows to specify the behavior of our system tailored to the specific needs of a user acting in different situations.

- **Q6. How can we evaluate the system developed for the domain of mobile police work?**

  The evaluation of the system we implemented is an integral part of our research. The behavior of the system should be assessed by an appropriate evaluation methodology on the basis of different use cases. We focus on quantitatively evaluating how well our system could have properties in terms of effectiveness, generic configurability and adaptability.

1.3 Contributions

The scientific contributions presented in this thesis concern the elicitation of information needs of police officers, the derivation of requirements for the design of an architecture, the modelling of dynamicity of a user's environment, the design of a generic architecture for contextualized information delivery, and the implementation as well as the evaluation of the system developed for the domain of mobile police work. Our main contributions thus are sixfold:

1. **Identification and representation of the information needs of police officers in the context of dealing with small-scale events.**

   Despite the large body of work in the area of context-aware services tailored to the needs of mobile users, few efforts take into account the specific needs of police officers acting in a given context. Based on our questionnaire-based study, we received a first-hand sense of how (and if) the information needs of police officers change in an evolving situation while carrying out their tasks.

2. **Requirements for the design of a generic architecture supporting delivery of relevant information in a contextualized setting.**

   From the observations and the analysis results following the study, we derived the requirements for our design of an architecture for providing relevant information to mobile users in a given context.

3. **An Architecture for contextualized information delivery.**

   Guided by the requirements, we designed the Contextualized Information Delivery Architecture (CIDA) and defined the functionality of single CIDA components. CIDA provides a rule-base mechanism which computes the relevance of information items given the contextual situations of mobile users.

4. **An ontology-based context model for representing the contextual situations of mobile users engaged in tasks aimed at certain events.**

   Compared with most of the context modelling that focuses on using physical contexts, we explored the context information beyond the spatial and temporal contexts. We established an ontology-based context model which consists of a generic ontology and a domain-specific ontology. Specifically, the generic ontology defines the basic concepts and is extensible to different domains, and the domain-specific ontology defines the details of general concepts and their properties specialized for the domain of mobile police work.

5. **A rule-based system for contextualized relevance assessment for the domain of mobile police work.**

   With the goal of showing the feasibility of CIDA, we developed the Contextualized Relevance Assessment System (CRAS) by taking into account the specific requirements of police officers. We started by defining a rule language (Message Rating Rule Language, MRRL) that was inspired by SWRL[4] (Semantic Web Rule Language) and was adapted for the purpose of updating the relevance of information items for a particular user in a given context. Note that MRRL is not only specific for our application domain. We implemented the Relevance Assessment Rule Engine (RARE) for executing MRRL rules, which were defined based on certain scenarios constructed in cooperation with police officers.

6. **Evaluation of the system on the basis of different and realistic use cases.**

   Compared to the current technology for evaluating context-aware systems, we focus in particular on the quantitative evaluation of the properties of our rule-based system. The behavior of CRAS is evaluated on the basis of different rule sets and datasets with regard to different configurations. The evaluations of CRAS in terms of precision and recall with respect to a gold standard demonstrate that: (1) CRAS can achieve reasonable precision and recall levels; (2) CRAS has generic configurability in the sense that it provides reasonable performance on forward use cases (test sets) by applying current rule sets; and (3) CRAS is adaptable to forward use cases with a modest effort.

1.4 Overview of this thesis

This thesis is structured in six main parts as follows.

Part I: Introduction. In Chapter 1, we provide the motivation for the work discussed in this thesis, and present the research questions and objectives, as well as the main scientific contributions.

Part II: Background. In Chapter 2, we overview related work with the background knowledge on Semantic Web technologies that could provide solutions for some of our problems and the state of the art of research and development in context-aware applications. In Chapter 3 we report on a questionnaire-based study of the work of police officers. This study allows us to later define requirements for an architecture design.

Part III: Architecture Design. In Chapter 4, we design the Contextualized Information Delivery Architecture (CIDA) following the requirements. In Chapter 5, we present an information item model and an ontology-based context model.

[4]http://www.w3.org/Submission/SWRL/

Part IV: Implementation. In Chapter 6, we define a rule language (MRRL) and explain the semantics of MRRL. In Chapter 7, we present the implementation of a rule engine (RARE), which is designed to execute a set of rules for computing the relevance of information for given users in a certain context. RARE supports us to develop a rule-based system (CRAS) which can assess the relevance of information according to the contextual situations of police officers.

Part V: Evaluation. In Chapter 8, we propose the questions to be addressed in the evaluation and construct the data for the evaluation based on given scenarios. Then, we evaluate the configurability of CRAS based on two use cases following our evaluation method. To further investigate the adaptability, in Chapter 9 we evaluate the behavior of CRAS on a different use case and present overall evaluation results for four sets of rules on three use cases.

Part VI: Conclusion and Future Work. In Chapter 10, we provide answers to the research questions raised in Chapter 1 and summarize our main scientific contributions. Further, we outline directions for future research.

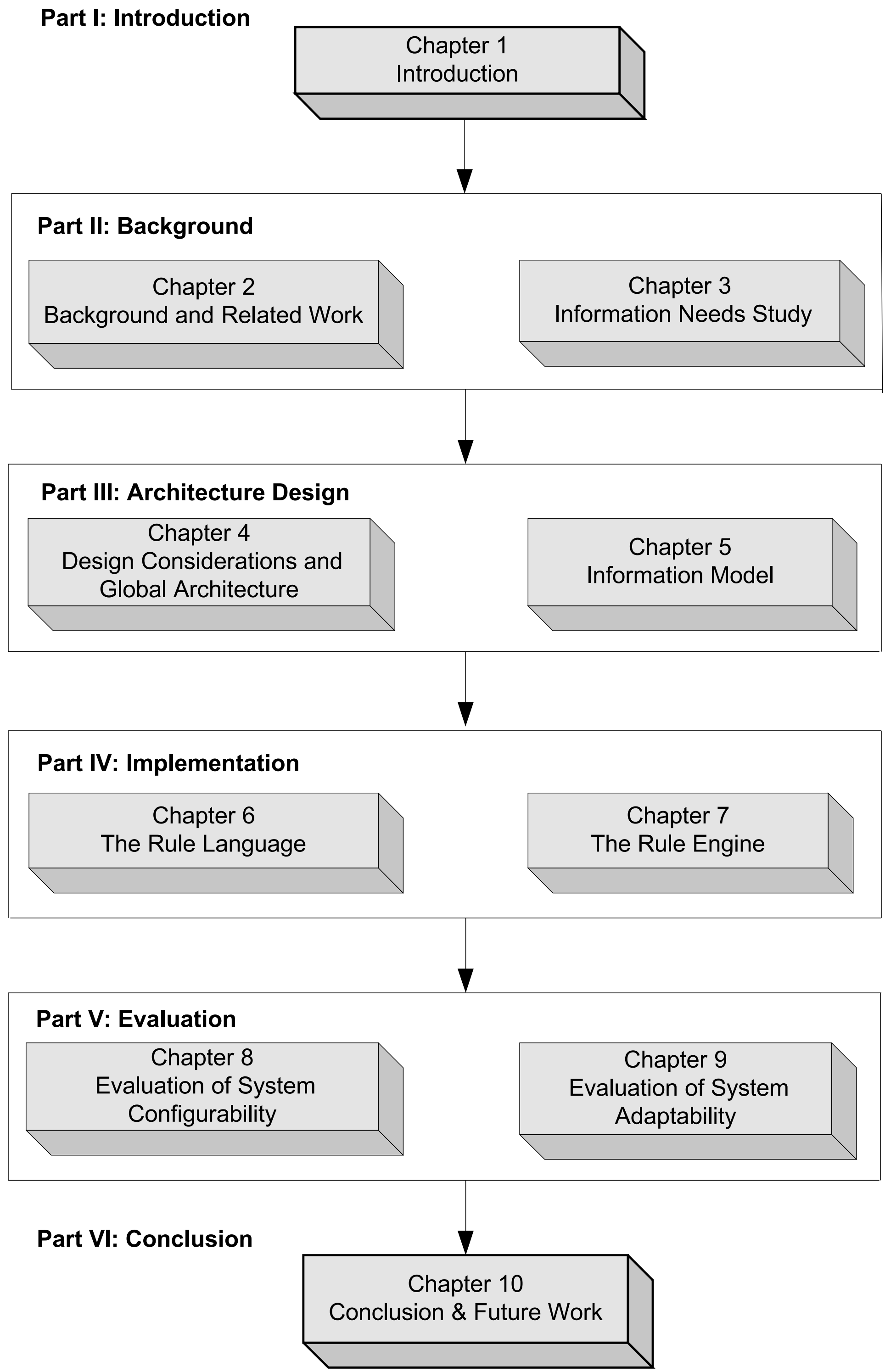

Figure 1.1: Outline of Thesis

Part II

Background

Chapter 2

Background and Related Work

This chapter gives a brief overview of technologies and applications related to our research. The goal is to explore advanced solutions for contextualized information delivery by presenting the state-of-art of Semantic Web technologies and reviewing previous research in the field of context-aware applications. We start by introducing background knowledge on Semantic Web technologies which could provide solutions for some of our problems. Then, we present an overview of research concerned with context modelling and context-aware systems. In particular, we investigate domain-specific applications in emergency response situations and rule-based architectures for context-aware services.

2.1 Semantic Web and Ontologies

The Semantic Web has been defined by the inventor of the World Wide Web (Berners-Lee et al., 2001) as:

"*The Semantic Web is not a separate web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation.*"

The goal of the Semantic Web is to solve the current limitation of the web by augmenting web information with a machine-processable representation of its meaning (Sabou, 2006), which allows us to publish and assess interlinked data on the web in a machine-understandable form (Antoniou and Harmelen, 2008). The explicit representation of meta-information, accompanied by domain theories (i.e. ontologies), will enable the web that provides a qualitatively new level of service (Davies et al., 2003). The Semantic Web can assist the evolution of human knowledge as a whole and will enable machines to comprehend semantic documents and data, not human speech and writings. One of the challenges of the Semantic Web is to provide a language that expresses both data and rules for reasoning about the data and that allows rules from any existing knowledge-representation system to be exported onto the web (Berners-Lee et al., 2001). Much of the focus of Semantic Web research is directed towards applying semantic annotation for knowledge management (Salesh, 2006; Uren et al., 2006). An architecture for Semantic Web-based knowledge management is provided by (Davies et al., 2003) to address the issues of knowledge acquisition, representation, maintenance and use.

2.1.1 Ontologies

Ontologies, which are a key enabling technology for the Semantic Web, were developed in artificial intelligence to facilitate knowledge sharing and reuse. More recently, the use of ontologies has also become widespread in fields such as intelligent information integration, information retrieval and knowledge management (Cimiano and Staab, 2004; Davies et al., 2003). The reason ontologies are becoming popular is largely due to what they promise: *a shared and common understanding of a domain that can be communicated between people and application systems* (Fensel, 2004). The most commonly quoted definition of an ontology is given by (Gruber, 1993) as:

"*An ontology is an explicit specification of a conceptualization*."

A *conceptualization*, refers to an abstract model of how people think about things in the world, usually restricted to a particular subject area. An *explicit specification* means that the concepts and relationships in the abstract model are given explicit names and definitions (Uschold and Gruninger, 2004).

(Studer et al., 1998) stated that: "*An ontology is a formal, explicit specification of a shared conceptualization*." This definition further requires that the conceptualization should express a *shared* view between several parties and also be expressed in a machine-readable format (i.e. *formal*). Shared conceptualizations include conceptual frameworks for modeling domain knowledge, content-specific protocols for communication among inter-operating agents, and agreements about the representation of particular domain theories.

In the knowledge sharing context, ontologies are specified in the form of definitions of representational vocabulary (Uschold and Gruninger, 1996). A more mathematical definition of ontologies was provided by (Cimiano, 2006), who also pointed out: "*Whereas 'ontology' was originally a science, 'ontologies' have received the status of resources representing the conceptual model underlying a certain domain, describing it in a declarative fashion and thus clearly separating it from procedural aspects*."

2.1.2 Ontology Languages

Ontologies are explicitly specified in a formal language. Our work presented in this thesis relied on the RDF(s) and OWL languages.

RDF(S). The Resource Description Framework (RDF)[1] and RDF Schema[2] are two W3C (World Wide Web Consortium) standards, which aim at enriching the web with machine-processable semantic data. They are designed to allow information and vocabularies to be developed in a decentralized fashion.

RDF was defined on top of XML to provide a data model and syntax convention for representing the semantics of data in a standardized interoperable manner. RDF provides a means of describing the relationships among resources (basically anything nameable by a Unified Resource Identification) in terms of named properties and values (McIlraith et al., 2001). The RDF data can represented as a collection of triples, each consisting of a subject, a predicate and an object (*S, P, O*). A set of such triples is represented by a labelled directed graph.

[1] http://www.w3.org/RDF/

[2] http://www.w3.org/TR/rdf-schema/

The RDF model is flexible because any object can play the role of a value, which amounts to chaining two labelled edges in a graphic representation (Davies et al., 2003). With the goal of allowing anyone to make statements about any resource[3], RDF supports a form of reification in which any RDF statement can be object or value of a triple, which means graphs can be nested as well as chained. When we federate information from multiple sources, the RDF data model is particularly convenient for us to represent all the data in a single, uniform way (Allemang and Hendler, 2008).

RDF Schema (RDFS) takes a step further into a richer representation formalism and introduces basic ontological modelling primitives into the web. In contrast to what XML Schema does for XML, in prescribing the order and combination of tags in an XML document, RDFS only provides information about the interpretation of the statements given in an RDF data model, but it does not constrain the syntactical appearance of an RDF description. In this way, RDFS lets developers define a particular vocabulary for RDF data and specify the kinds of objects to which these predicates can be applied (Davies et al., 2003). Within RDFS, we can define basic ontology elements such as classes and their hierarchy or properties with their domain, range and hierarchy (McBride, 2004). As such, RDF(S), the combination of RDF and RDFS, is well suited for expressing simple ontologies.

OWL. The Web Ontology Language (OWL)[4] is a semantic markup language for publishing and sharing ontologies on the World Wide Web. OWL has more facilities for expressing meaning and semantics than XML, RDF, and RDFS, and thus OWL goes beyond these languages in its ability to represent machine-interpretable content on the web. OWL adds more vocabulary for describing properties and classes[5]: among others, relations between classes (e.g. disjointness, union, intersection), cardinality, equality, richer typing of properties, characteristics of properties (e.g. transitivity, symmetry), and enumerated classes.

OWL provides three expressive sublanguages: OWL Full, OWL DL and OWL Lite (McBride, 2004).

- **OWL Full**: The entire language is called OWL Full, and uses all the OWL languages primitives. OWL Full is meant for users who want maximum expressiveness and the syntactic freedom of RDF with no computational guarantees.
- **OWL DL**: OWL DL (short for: Description Logic) is a sublanguage of OWL Full which restricts the way in which the constructors from OWL and RDF can be used (Antoniou and van Harmelen, 2009). OWL DL supports those users who want the maximum expressiveness while retaining computational completeness (all conclusions are guaranteed to be computable) and decidability (all computations will finish in finite time).
- **OWL Lite**: An even further restriction limits OWL DL to a subset of the language constructors. For example, OWL Lite excludes enumerated classes, disjointness statements and arbitrary cardinality (among others). OWL Lite supports those users primarily needing a classification hierarchy and simple constraints.

[3] http://www.w3.org/TR/2002/WD-rdf-concepts-20020829/
[4] http://www.w3.org/TR/owl-ref/
[5] http://www.w3.org/TR/2004/REC-owl-features-20040210/

2.2 RDF Query Languages and Engines

2.2.1 Query Languages

Accessing and querying RDF data on distributed sources is one of the fundamental tasks for many Semantic Web applications. Several languages for querying RDF data have been proposed and implemented, some in the lines of traditional database query languages such as SQL or OQL; others based on logic and rule languages (Angles and Gutierrez, 2005). (Haase et al., 2004) have presented a comparison of six representative query languages for RDF including RQL[6], SeRQL[7], TRIPLE[8], RDQL[9], N3 (Notation3)[10], and Versa[11], highlighting their common features and differences. Besides the above mentioned query languages, SPARQL (Simple Protocol and RDF Query Language) is a W3C Recommendation query language for RDF. We present SPARQL here since we used it in our work and briefly introduce other representative RDF query languages.

SPARQL. SPARQL[12] is the standard query language for querying RDF data based on graph pattern matching.

A SPARQL query consists of three parts. The *pattern matching part*, includes several interesting features of pattern matching of graphs, like optional parts, unions of patterns, nesting, filtering values of possible matchings, and the possibility of choosing the data source to be matched by a pattern. The *solution modifiers*, once the output of the pattern has been computed (in the form of a table of values of variables), allow to modify these values applying classical operators like projection, distinct, order, limit, and offset. Finally, the *solutions* of a SPARQL query can be: whether or not a solution exisits, selections of values of the variables which match the patterns, construction of new triples from these values, and descriptions of resources (Pérez et al., 2009).

Specifically, a CONSTRUCT query matches a graph pattern against one or more input graphs. The resulting variable bindings are embedded into a graph template in order to generate new RDF data. (Schenk and Staab, 2008) proposed *networked graphs* as a declarative mechanism to define RDF graphs both extensionally, by listing statements, and intensionally using views on other graphs. This proposed mechanism allows one to use almost all of the expressiveness of SPARQL CONSTRUCT queries, including negation and recursive views. (Polleres, 2007) discussed an extension of SPARQL towards recursion by allowing *bNode-free-CONSTRUCT* queries as part of the query dataset, which may be viewed as a lightweight, recursive rule language on top of of RDF.

RQL. RQL is a typed language following a functional approach, which supports generalized path expressions featuring variables on both nodes and edges of the RDF graph (Haase et al., 2004). RQL has abilities to smoothly combine schema and data querying while ex-

[6] http://139.91.183.30:9090/RDF/RQL/
[7] http://www.openrdf.org/doc/sesame/users/
[8] http://triple.semanticweb.org/
[9] http://www.w3.org/Submission/RDQL/
[10] http://www.w3.org/DesignIssues/Notation3
[11] http://www.xml3k.org/Versa/Specification
[12] queryhttp://www.w3.org/TR/rdf-sparql-query/

ploiting the taxonomies of labels and multiple classification of resources (Karvounarakis et al., 2002).

SeRQL. SeRQL[13] stands for Sesame RDF Query Language, coming with Sesame query engine. It combines the best features of several existing languages, most notably RQL, RDQL and N3. Some of SeRQL's most important features are (Broekstra and Kampman, 2006): (1) Graph transformation; (2) RDF Schema support; (3) XML Schema datatype support; (4) Expressive path expression syntax; and (5) Optional path matching.

2.2.2 Query Engines

Sesame. Sesame is an architecture for efficient storage and expressive querying of large quantities of metadata in RDF and RDF Schema (Broekstra et al., 2002). Sesame's design and implementation are independent from any specific storage device. Thus, Sesame can be deployed on top of a variety of storage devices, such as relational databases, triple stores, or object-oriented databases, without having to change the query engine or other functional modules. Sesame offers support for concurrency control, independent export of RDF and RDFS information. Sesame supports its own query language SeRQL. In addition, it provides a SPARQL engine (Bernstein et al., 2007). We used Sesame to execute SPARQL queries.

Jena. Jena is a leading Semantic Web toolkit for Java programmers, which provides a rich Model API for manipulating RDF graphs (Carroll et al., 2004). Jena supports a Semantic Web query language, RDQL, that can be used either on top of materialized graphs, or on the virtual results of RDFS or OWL reasoning.

2.3 RDF Rule Languages

Since interoperability is one of the primary goals of the Semantic Web, developing a language for sharing rules is often seen as a key step in reaching this goal (O' Connor et al., 2005). The goal of sharing rule bases and processing them with different rule engines has resulted in RuleML[14], SWRL[15], Metalog (Marchiori and Saarela, 1998), TRIPLE[16] and other standardization efforts[17]. Here, we briefly introduce SWRL and TRIPLE.

SWRL. Semantic Web Rule Language (SWRL) is based on a combination of the OWL DL and OWL Lite sublanguages of the OWL Web Ontology Language with the Unary/Binary Datalog RuleML sublanguages of the Rule Markup Language. SWRL includes a high-level abstract syntax for Horn-like rules in both the OWL DL and OWL Lite sublanguages of OWL. The rules can be used to infer new knowledge from existing OWL knowledge bases.

[13] http://www.openrdf.org/doc/sesame/users/
[14] http://www.ruleml.org/
[15] http://www.w3.org/Submission/SWRL/
[16] http://triple.semanticweb.org/
[17] http://www.w3.org/2004/12/rules-ws/cfp

In common with many other rule languages, SWRL rules are written as antecedent-consequent pairs. In SWRL terminology, the antecedent is referred to as the rule body and the consequent is referred to as the head. The head and body consist of a conjunction of one or more atoms (O' Connor et al., 2005). Using human-readable syntax, a SWRL rule asserting that the combination of the *hasParent* and *hasBrother* properties implies the *hasUncle* property would be written as:

hasParent($?x1$,$?x2$) $\wedge$ hasBrother($?x2$,$?x3$) $\rightarrow$ hasUncle($?x1$,$?x3$)

TRIPLE. TRIPLE is a rule-based query, inference, and transformation language for RDF. TRIPLE is based on Horn logic and borrows many basic features from F-Logic (Kifer et al., 1995). RDF triples (S,P,O) are represented as F-Logic expressions S [P $\rightarrow$ O], which can be nested. One of the most important differences to F-Logic is that TRIPLE does not have a fixed semantics for object-oriented features like classes and inheritance. Its layered architecture allows such features to be easily defined for different object-oriented and other data models like UML, Topic Maps, or RDF Schema (Sintek and Decker, 2002).

2.4 Context Definitions and Categories

The notions of "context" has been interpreted by many researchers in different fields from various perspectives. Therefore, it is very difficult to present a standard definition of context. In the area of computer science, previous attempts to define and provide a characterization of context are illustrated in the following:

Definition by Examples. At the early stage, many researchers defined context by examples and enumerated context elements. (Schilit et al., 1994), who first introduced the work of context-aware computing, refer to context as location, identities of nearby people and objects, and changes to those objects. In the same vein, (Brown et al., 1997) defined context as location, identities of the people around the user, the time of day, season, temperature, etc. Furthermore, (Dey and Abowd, 1999) mentioned more types of information as the user's emotional state, focus of attention, location and orientation, date and time, objects, and people in the user's environment. However, for the use of context, these definitions cannot help users to determine whether given information not listed in the definition is context or not.

Definition by Synonyms. Another common way of definition has simply provided synonyms for context, for instance, referring context to as the environment or situation. Some consider context to be the user's environment/situation (Chen, 2004; Hull et al., 1997), while others consider it to be the application's environment (Moran and Dourish, 2001; Ward et al., 1997). Such indirect definitions by synonyms fail to establish any fundamental basis for their construction, since they are basically driven by the ease of implementation (Zimmermann et al., 2007).

To address the limitations in the early definitions of context, (Dey and Abowd, 2000) provided a general definition which have become widely accepted by researchers:

"*Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves*."

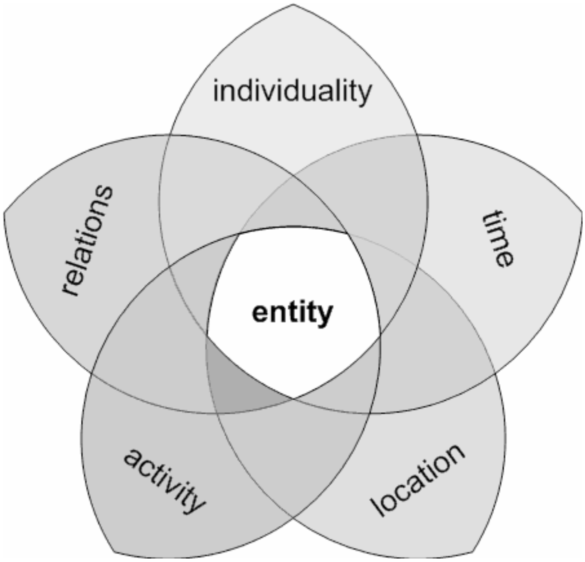

Figure 2.1: Five Fundamental Categories for Context Information (Zimmermann et al., 2007)

Categories of Context Information. One popular way to classify context information is the distinction of different context dimensions. Many researchers referred to these dimensions as external (physical) and internal (logical) (Baldauf et al., 2007; Hofer et al., 2003; Prekop and Burnett, 2003). The external/physical dimension refers to the context that can be measured by hardware sensors, whereas the internal/logical dimension is mostly specified by the user or captured by monitoring user interactions, such as the users' intentions and cognitive abilities. The external context such as location and temperature is by far the most frequently used context. (Dey and Abowd, 1999) considered four primary pieces of context, i.e. location, identity, time, and activity, as the first level of context for characterizing the situation of a particular entity, while all other types of context which can be indexed by primary ones are on the second level. Also, they considered the user's task as an important part of the context given that user's actions are generally goal-driven. The central role of the task is shared by (Crowley et al., 2002; Kofod-Petersen and Cassens, 2006; Neerincx and Streefkerk, 2003), who introduced the term "activity" to accurately capture the observation that the user is concerned with several tasks simultaneously. By the extension of the above mentioned four primary types of context, any information describing an entity's context falls into one of five categories as shown in Figure 2.1 (Zimmermann et al., 2007).

2.5 Context Modelling

Modelling context information is considered as a fundamental issue in developing applications adaptable to changing context information. Because the context model captures the relevant context variables, it represents the semantics of the contextual information and identifies how certain types of context can be manipulated (Vieira et al., 2011). A large part of research investigates approaches for context modelling including (Baldauf et al., 2007;

Strang and Linnhoff-Popien, 2004):

- Key-value models, which use simple key-value pairs to define the list of attributes and their values to describe context information;
- Markup scheme models, using a variety of markup languages including XML;
- Graphical models, relying on the Unified Modelling Language (UML);
- Object-oriented models, which model context types by using various objects;
- Logic-based models, which represent the contextual information in a formal way as facts by employing general purpose reasoning techniques;
- Ontology-based models, constructing a context ontology for defining basic concepts in the domain and relations among them in order to share contextual knowledge among users and services.

Compared to the above mentioned approaches, ontologies, which represent a sets of concepts within a domain and the relationships between those concepts, are considered as most prominent approaches for modelling context information due to their high and formal expressiveness and the possibilities for applying ontology reasoning techniques (Baldauf et al., 2007; Chen and Kotz, 2000; Strang and Linnhoff-Popien, 2004). More recently, ontologies are developed to identify and monitor the relationships among high level context data, that is, the so-called SAW (Situation Awareness) ontology (Matheus et al., 2003). Specifically, situations are external semantic interpretations of context (Dobson and Ye, 2006). According to (Neerincx et al., 2003), situation awareness is heavily dependent on the type of task the user has to perform and the level of routine a user has in executing the task. We consider existing ontologies for modelling the context or situation that are most influencing for our work: SOUPA (Chen et al., 2005), SOCAM (Gu et al., 2004), FLAME (Weiβenberg et al., 2006), SAWA (Matheus et al., 2005), and BeAware! (Baumgartner et al., 2010). We summarize their characteristics and limitations in Table 2.1.

The lessons learned from this comparison are:

- **Expressiveness and knowledge sharing**. These ontology-based context models make use of the expressiveness of ontologies to describe complex context data (e.g. *computational entity* in SOCAM and *agents* in SOUPA), and provide a formal semantics to context data in order to facilitate knowledge sharing.
- **Inference**. These models exploit the reasoning power of ontolgoies to derive new knowledge and facts. For example, in SOCAM, the *Context Reasoning Engine* reasons over the knowledge base to infer deduced context, resolve context conflicts and maintaining the consistence; in FLAME, the situation of a user is derived from the sensed context by using inference engines.
- **Upper ontology and Domain ontology**. The upper ontology defines the basic concepts and relationships for context information; and the domain ontology specifies the details of these concepts adapted to a certain domain. The evaluation of the upper ontologies in these context models show that: (1) SOUPA's approach to spatio-temporal

Name	**Captured Context & Characteristics**	**Missed Context & Limitations**
SOUPA (Standard Ontology for Ubiquitous and Pervasive Application)	*Captured Context*: The SOUPA core – the description of basic concepts of person, agents, events, space and time. The SOUPA extension – the extension of the upper ontology by incorporating the agents and their goals for expressing thematic roles of objects. *Features*: Supporting for inferring context knowledge (e.g. user intentions, roles and duties) that cannot be easily acquired from the physical sensors.	Attributes, relations, events, and situations are not explicitly anchored in the SOUPA Core.
SOCAM (Service-Oriented Context-Aware Middleware) Context Ontology	*Captured Context*: An upper ontology – the capture of general context knowledge about the physical world, i.e. location, person, activity, and computational entity. A domain-specific ontology – Vehicle-domain and home-domain ontology. *Features*: Supporting for rule-based inference; the longitude and the latitude of a location can be specified.	There are no explicit relationship between person and events. The lack of concepts for determining the meaning of a situation.
FLAME Olympic 2008 Ontology	*Captured Three Levels of Context*: The first level of sensor values; the higher level of abstraction; and the situation level of the user's demand at a certain time. *Features*: Deriving the situation of a user from the actual context information and context history; translating specific contexts into logical situations.	It is highly specific for the domain of Beijing Olympics. It is does not model activities and the task at hand.
SAWA (Situation Awareness Assistant)	*Captured Context*: An upper ontology – the *Situation* class defines a situation to be a collection of *Goals (standing relation), Objects* and *Relations*. Domain-specific extensions in the domain of military and the domain of supply logistics. *Features*: SAWA can be adapted to handle domain-specific situations by readily extending the core language. The SAWA upper ontology uses SWRL for deriving relations among objects using rules.	The lack of qualitative approaches to the representation of time, space and situation types in the domain-specific ontology.
BeAware! ontology	*Captured Context*: An extension of SAW ontology. *Features*: The combination of domain-specific and domain-independent spatial framework; the incorporation of spatio-temporal relation types and the representation of situation and situation types.	As an assistance for an operator, it does not incorporate appropriate actions and highlight the effects these actions can incur.

Table 2.1: A Comparison of Ontology-based Context Models

representation is clearly more sophisticated; (2) SOCAM uses the ontology reasoning engine efficiently; (3) FLAME has an advantage in representing the three levels of context; and (4) the SAWA upper ontology which origins from the field of SAW can satisfy the evaluation criteria of universality and articulation very well (Baumgartner and Retschitzegger, 2006). To tackle the limitation of lacking of space and time and situation types in the upper SAWA ontology, the BeAware! SAW core ontology incorporates the spatio-temporal *primitive* relations and represents the situation types for the situation assessment.

2.6 Context-awareness

Compared to the information services in traditional office environments, context-awareness is an important concept for the usability of pervasive systems as it reduces the need for explicit inputting and it takes advantage of changes in information relating to users, devices and environments. Context-awareness also refers to other terms, such as adaptive (Efstratiou et al., 2001), responsive (Bellotti and Edwards, 2001), context-sensitive (Yau et al., 2002) and situation awareness (Meissen et al., 2005; Wickens, 2008). Most of the definitions of context-aware computing fall into two categories (Dey, 2000):

1. **Using context**. Context-awareness means that one is able to use context information (Hong et al., 2009b). (Hull et al., 1997; Pascoe et al., 1999) define context-awareness to be the use of context to automate a software system, to modify an interface, and to provide maximum flexibility of a computational service.
2. **Adapting to context**. Context-aware applications as applications that can adapt their functionality to different situations and be more receptive to users' needs (Ranganathan and Campbell, 2003b; Schilit et al., 1994; Ward et al., 1997).

(Chen and Kotz, 2000) have a different perspective on how a mobile application can take advantage of context. They gave two definitions of context-awareness: (1) Active context awareness – an application automatically adapts to discovered context, by changing the application's behavior, and (2) passive context-awareness – an application presents the new or updated context to an interested user or makes the context persistent for the user to retrieve later. (Dey, 2000) introduced the user's task as an important concept through the definition of context-awareness and stated that:

"*A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task.*"

2.7 Context-aware Architectures and Systems

In the early stage of mobile computing research, location was typically used to approximate context and to implement context-aware applications. Location-aware systems have been developed from the Active Badge Location System (Want et al., 1992), which is considered as one of the first context-aware applications, to current location aware infrastructures, such as an indoor location sensing system (Harter et al., 2002). (Hightower and Borriello, 2001) presented a survey of location-aware systems.

In recent years, more and more approaches are moving beyond the exploitation of a mere temporal and spatial notion of context towards considering any information characterizing the context in a broader sense, in particular, information derived from sensors (Raento et al., 2005; Yang et al., 2007). However, approaches such as the ones mentioned above have not taken into account the fact that information needs can change as the situation in which users are involved evolves. Along these lines, (Meissen et al., 2005) presented a model allowing to handle various contexts and situations in information logistics. This model has been utilized in the MeLog (Message Logistics) system in order to infer information about a user's situation from sensor data by matching this information to predefined typical situations.

The existing context-aware systems and architectures are mainly related to four categories (Hong et al., 2009b):

- **Middleware**. The middleware allows systems to acquire contextual information easily, to reason about it using different logics and then to adapt themselves to changing contexts (Lassila and Khushraj, 2005). One of typical middlewares is SOCAM (Service-Oriented Context-Aware Middleware) introduced by (Gu et al., 2005).
- **Network for providing context-aware computing**. Many research studies are conducted to offer appropriate networks for providing context-aware computing (Wood et al., 2008). For example, (Balasubramaniam and Indulska, 2004) proposed a vertical handover mechanism which can support seamless computing in wireless networks.
- **User infrastructure**. Dynamic environments set special requirements for the usability and acceptance of context-aware systems. Therefore, research of user interface (UI) and usability of handheld device are carried out (Conati and Maclaren, 2009; Hong et al., 2009b; Hosseiny et al., 2011). In UI research, user modelling and human-computer interaction for considering the emergence of ubiquitous and mobile computing environments have been presented (Dey and Newberger, 2009; Kahl et al., 2011; Song et al., 2011). The usability research involves investigating the user needs based on user interviews, field evaluations with users, and expert evaluations of context aware services (Antifakos et al., 2005; Choi et al., 2009; Damián-Reyes et al., 2011; O'Neill et al., 2007)
- **Application and service**. There are many types of context-aware applications, providing the users with a smart environment such as a home or hospital (Hong et al., 2009a; Konstantinou et al., 2010; Sánchez et al., 2008). Besides, context-aware applications include decision support systems, communication systems, m-commerce and web service systems (Jancsary et al., 2011; Simoes and Magedanz, 2010)

2.8 Context-aware Applications in Emergency Situations

In the last few years, mobile incident support systems have gained increasing attention and interest by fire and rescue services. Mobile incident support systems consist of a set of applications integrated into one system with the objective to support a range of tasks in the operative response work. Mobile incident command systems include applications for navigational support (Zlatanova and Baharin, 2008), access to maps, predefined response plans, property information and access to hazardous material databases (Landgren, 2007). In this vein, an increasing number of context-aware applications aim to support human operators of large-scale control systems in order to timely and correctly resolve or even prevent critical situations. For example, the *P-Info* system developed by Dutch Police provides mobile location-enabled access to mission-critical information for district police officers[18] and the SHERPA project is aiming at the standardization of the Geo-Information (GI) provision for all the 25 police regions in the Netherlands (Borkulo et al., 2006).

Overall, we can distinguish at least three types of context-aware systems which are targeted at supporting responders involved in emergency management. Firstly, Geo-Information Systems (GIS) provide powerful decision support and help to find optimal solutions to complex problems in emergency management (Aydinogly et al., 2009). To help responders easily obtain geo-data from distributed databases to accomplish their emergency tasks, much research focuses on the integration of geo-information through interoperable systems (Foerster et al., 2011; Harrison et al., 2006; Zlatanova and Dilo, 2010). Secondly, we have systems which aim to distribute tasks during mobile surveillance in an optimal way. An example of this is the system designed in the Dutch MultimediaN project which is aware of officer availability, task priority and proximity to the incident location (Streefkerk et al., 2009). Also, a set of applications were built on an event-driven architecture for sending and receiving messages during crisis management on the basis of predefined sets of decision rules (Chandy et al., 2003). Such context-aware notification systems can predicate appropriate moments for interruption based on certain contexts in order to provide task allocation advice (Bailey and Iqbal, 2008; Horvitz et al., 2005). Lastly, we have systems with the goal of improving the communication between team members, i.e. team-awareness (Streefkerk, 2011), such as the We-Centric service prototype which provides hints and reasons to contact police colleagues (Steen et al., 2009); and a method proposed in (Netten and van Someren, 2011) as basis for a software system that improves text or voice-based communication for fire fighters; and also an Spatial Data Infrastructure (SDI) presented in (Scholten et al., 2008) for assisting in administration and accordingly advise for changes of plans.

Emergency response requires an efficient information exchange for optimal intra- and inter-organizational emergency management processes. However, due to the lack of consistent data standards, it is difficult for emergency response systems to fulfill the collaborative management. To tackle this challenge, a number of emergency data standards have been developed to address the issues of interoperability when data is passed between applications and devices, including a XML-based data model that was developed following Activity Theory (Chen et al., 2008) and a data model derived from the emergency response procedure for organization of dynamic data (Dilo and Zlatanova, 2010; Zlatanova, 2010). In particular, (Xu et al., 2008) presented the modelling of disaster management processes both in OWL-DL and in UML.

To assess the effectiveness of context-aware applications, much research effort is targeted at how to translate evaluation methods for desktop computing to mobile professional environments (Zhang and Adipat, 2005). The changing context of emergency responders sets high requirements for evaluation of context-aware systems in incident response. To evaluate a context-aware mobile support system, a longitudinal field study and experiments in the police domain were conducted in (Streefkerk, 2011) following the Situated Cognitive

[18] http://www.geodan.com/markets/public-order-and-safety/p-info/

Engineering method (Neerincx et al., 2006). Also, (Fiore and Beinat, 2009) presented an evaluation research conducted for a Dutch police pilot initiative in order to identify critical points in the adoption of new mobile and location-aware applications.

2.9 Rule-based Context-aware Architectures

The behavior of context-aware applications is required to be adaptable to the users' context without explicit user intervention. One common and simple way to specify the behavior of the applications in different contexts is using rules (Ranganathan and Campbell, 2003b). These rules consist of (1) conditions for identifying a specific context and (2) actions to be executed when all conditions are satisfied (Nishigaki et al., 2005). Whenever the context of a user's environment changes, the conditions in corresponding rules can be evaluated and actions are executed if all conditions are met.

Considerable efforts have been made in context-aware applications relying on a rule-based architecture, which allows users to re-configure the system according to evolving needs. Table 2.2 shows representative rule-based context-aware architectures.

Architecture	**Rule Language**	**Rule Checking**	**Application Domain**
Gaia	DAML+OIL	Type-checking of context predicates	Smart space
DMS-CA	XML specifications	Event-driven rule checking	Smart building
ANS	ECA and ECA-DL	Consistence checking	Indoor personalized notifications
CoBrA	OWL	A personalized access control model	Intelligent meeting room
CADEL framework	CADEL	Consistency check module	Information appliances at home

Table 2.2: Examples of Rule-based Architectures for Context-aware Applications

1. **Gaia**. Gaia is a middleware infrastructure to enable active spaces (Ranganathan and Campbell, 2003a), which supports the evaluation of pre-defined rules written in first-order logic in order to invoke appropriate methods in different contexts. The developers claimed that Gaia is a generic architecture which provides an easy way for developers to specify how an environment should automatically respond to different contexts. The DAML+OIL ontology language (a predecessor of OWL) is the basis of the context model of Gaia. In Gaia, reasoning for deriving new context data is performed by means of rule-based inferencing and statistical learning (Bettini et al., 2010).

2. **DMS-CA**. Data Management System-Context Architecture (DMS-CA) is an event-driven architecture for executing contextual rules defined using XML specification (Herbert et al., 2008). DMS-CA has been applied in a smart building environment.

However, one drawback is that the rules are not easily modified since the conditions of rules only support limited vocabularies for describing the context.

3. **ANS**. The Awareness and Notification Service (ANS) enables to rapidly build applications that offers notifications according to the users' preferences and current contexts (Etter et al., 2006). ANS takes a rule-based approach based on the Event-Condition-Action (ECA) pattern. An ECA rule-based framework supports adaptive, flexible and dynamic services that are modifiable in run-time (Goh et al., 2001; Toninelli et al., 2006). Specifically, the ANS infrastructure supports the derivation of high-level situations in context-aware applications by using a combination of UML class diagrams and OCL (Costa et al., 2007; Louwsma et al., 2006). To guarantee the consistence of rules, (Daniele et al., 2007) has proposed to integrate the Jess library into an ECA rule-based architecture in order to manage entity relationship reasoning. They also have reported on the mapping of ECA Domain-specific Language (ECA-DL) rules used to express the context-aware reactive behaviors into the Jess language.
4. **CoBrA**. Context Broker Architecture (CoBrA) is an agent-oriented architecture that uses the Semantic Web languages (OWL) to model ontologies of context, to reason with context in a smart space, and to define a policy language for users to control the sharing of their context information (Chen, 2004). Go one step further, in order to bridge the semantic mismatch between different domains, a Context Management Framework (CMF) was designed for context-processing entities that support tailored applications and services in a multi-domain mobile environment. CMF uses an OWL-DL reasoner and benefits from the reasoning methods of semantic descriptions and matching techniques (van Kranenburg et al., 2006).
5. **CADEL framework**. A framework and a context-aware rule description language (CADEL) has been proposed to simply and intuitively specify feasible rules for context-aware control of information appliances (Nishigaki et al., 2005). This architecture provides a mechanism which automatically detects a rule conflict and rules can be defined by the user on the mobile device using an automatically generated interface. In this way, it would be easy for users who have limited IT specialists to define rules by choosing an appropriate combination of conditions and actions. However, it is not easy to modify the rules because the users have to re-define the syntax of CADEL if they want to add new words in the conditions.

2.10 Conclusion

In this chapter we have started with the introduction of background knowledge about the Semantic Web with respect to ontologies and languages, since these Semantic Web technologies could offer solutions for some of our problems. Then, we have presented an overview of the state-of-the art of context-aware systems and applications. We enumerated the most acknowledged definitions of context and context-awareness. Also, we summarized the approaches for context modelling and compared the several ontology-based context models. We described existing typical context-aware systems and discussed the applications in the domain of emergency situations. Finally, we presented some popular rule-based architectures for context-aware services.

Chapter 3

Information Needs Study in Mobile Police Work

In this chapter we present a questionnaire-based study in mobile police work. This study allows us to identify and represent the typical information needs of police officers in the context of given scenarios. This study was published in (Hu et al., 2010).

3.1 Motivation

Our research focuses on the delivery of contextualized information that can support mobile users in performing their task. In the context of the MOSAIC project[1], we consider police officers involved in mobile police work as our end-users. The specific goal of our research is to deliver relevant information contextualized to the current situation and needs of police officers. One important prerequisite for achieving this goal is the collection of the information needs of police officers in relation to their task at hand. However, it is not a trivial task to capture and reveal the information needs of police officers for two reasons.

First, with the aim of dealing with events, police officers are often involved in quickly changing situations which are fundamentally different from traditional work environments, such as the standard office environment. Thus, their information needs are largely determined by various context information such as the task at hand. Second, since actual work activities of police officers rely significantly on experience and their work processes are hard to describe in precise terms (Fiore and Beinat, 2009), the information needs cannot be collected by asking police officers directly to describe what they require to know.

This chapter proceeds by summarizing the previous work in Section 3.2 and presenting the research questions in Section 3.3. Next, it provides details about the method and procedure of the study in Section 3.4. Then, this chapter presents the results gained from the study in terms of relevance rating measurements in Section 3.5 and the expert agreement measurements in Section 3.6. Finally, this chapter concludes with a discussion of this study in Section 3.7.

[1] http://www.icis.decis.nl/index.php/lang-nl/projects/id-and-valorization/187-mosaic

3.2 Previous Work

In order to tackle the above challenge, we interacted throughout the research with the Dutch Police to gather the requirements and also to find solutions for those requirements. Using the experience from an indicative user experiment conducted in May, 2009 with domain experts, we collected basic requirements for the design of an information delivery system which supports mobile police work. First, the system should fully exploit the context of the task at hand and the activities that users are involved in, in order to meet the specific information needs of the police officers. Second, the system should select relevant but not too much information. Last but not least, the system should show real-time behavior.

Police work by its very nature is dynamic, complex and stressful. As part of their day-to-day routine, police officers have to deal with a myriad of fast-changing, complex and demanding problems (Luen and Al-Hawamdeh, 2001). Police officers' activities include three general processes: emergency aid, criminal investigation and law enforcement (Streefkerk, 2011). A set of user studies and police requirements analysis have shown that mobile police officers need to have situation awareness support, team awareness and task allocation support (Baber et al., 2001; Marcus and Gasperini, 2006; Parasuraman et al., 2008; Stijnman, 2004; Streefkerk, 2011). We have made an effort to understand the routine police work from interviews in police organization. We learned that much of the routine work involves the management of traffic, conducting investigations, questioning suspects, collecting evidence, preventing crime and other types of daily activities (Nuutinen and Norros, 2009). Therefore, we decided to collect the information needs of police officers in the context of handling small-scale events. From the analysis of a realistic "small" scenario (i.e. a car collision scenario) provided by a domain expert in the MOSAIC project, we found that in general the procedure of executing the task to deal with a certain incident consists of several sub-activities. Then, in cooperation with domain experts we grouped the sub-activities into phases such that we expect that within a specific phase there will be specific information needs. Along with this, we also grouped the information items into information types that are expected to be characteristic for these information needs.

Definition of Phases and Information Categories. On the basis of the above findings, we obtained a list of consecutive phases which is understood as a period in which police officers are engaged in some logical part of a task in the course of dealing with a certain small-scale event:

Departure. In the departure phase, a police unit is dispatched by the CCR (Command and Control Room) and departs speedily for the incident spot.

Arrival. After arriving at the spot, police officers decide on an action plan and start to take control of the surrounding situation, e.g. perform traffic management in the case of a car collision.

Initial investigation. In the investigation phase, police officers focus on investigating the targeted objects following the standard routine procedures, for example, inspecting a location or some object, or interviewing a witness.

Further investigation. After the situation has been controlled, police officers continue to gather evidence once new clues can be found.

Moreover, we asked the domain experts which types of information police officers often deal with to make their decisions. The experts enumerated several main types of information. We classified those different types of information into five main categories with their subcategories. Those information categories partially derived from a set of reference categories developed in the Netherlands (ACIR, 2005) and the structure of the Common Altering Protocol (CAP)[2]. In total, there are nine categories of information which are listed as follows:

Navigation information. Information about how police officers can navigate to arrive at the spot of the incident in the fastest way.

Personal safety. Facts explaining the nature of danger for their situation.

Subject information. Background information about the subjects they are approaching. Such information consists of four subcategories: (1) general personal background; (2) presence of criminal records; (3) social relations; and (4) medical history.

Non-targeted event information. Ongoing activities of colleagues who are involved in other, possibly related events. Such information includes (1) attributes of nearby incidents and (2) priority activities of colleagues.

Incident evidence. Evidence relevant to the targeted event.

3.3 Research Questions

Although by collecting the basic requirements explained in Section 3.2, we improved the understanding of police work, we still need to go one step further in determining what information policemen require in specific phases they are involved in. As can been seen in Figure 3.1, once a car collision incident happens, information will be received by the dispatchers in the CCR from various sources. A critical problem for the CCR is then arises: "What information is relevant for police offices acting in a specific contextual situation?"

We therefore carried out a questionnaire-based study with police officers to address the following research questions:

- Q1. **Are information needs phase-specific?**
- Q2. **Do the different categories of information influence the information relevance within in a certain phase?**
- Q3. **How can the relevance of information be predicted depending on the specific phase and category?**

We used a number of constructed scenarios and then measured the relevance of information in those scenarios. The findings following from the study address the three research questions.

[2]http://docs.oasis-open.org/emergency/cap/v1.2/pr03/CAP-v1.2-PR03.pdf

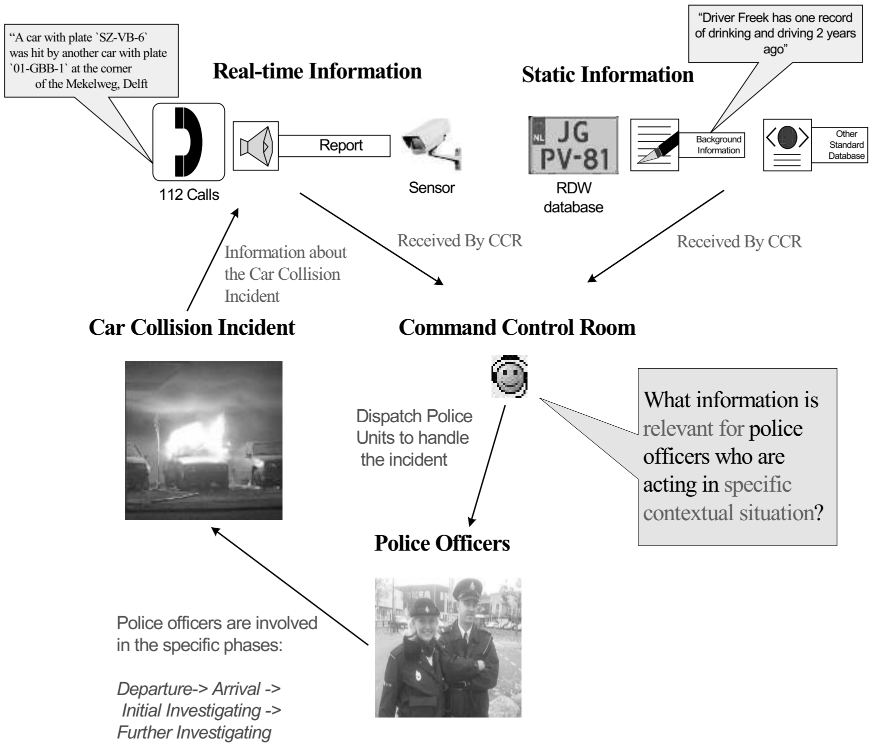

Figure 3.1: Illustration of a Car Collision Incident

3.4 Study Setup

The questionnaire had as its goal to elicit the information needs of police officers in incident response work with the questionnaire. We aim to receive a firsthand sense of how (and if) information needs of police officers change over phases while carrying out their tasks.

3.4.1 Scenario Construction

We defined two scenarios in cooperation with domain experts. Both of the scenarios consist of four routine incidents. Two of these incidents – *a car collision incident* and *a fallen painter incident* – are considered as the main events targeted by the subjects in the study (police officers), who are supposed to handle these events. During the course of handling one main incident, three further events take place on the side: *a handbag robbery*, *a confused old man who has lost his way* and the "other" main event. When police officers are focusing on a main event, the other three events can be regarded as constituting the broader context.

The description of scenarios was confirmed as realistic by the domain experts, who explained how some unrelated events could become relevant for a police unit if they happen close-by, thus potentially having some influence on the targeted event. Inspired by this point, we tried to approximate realistic settings in which several events with different emergency levels take place almost at the same time.

Incidents. Around 22:00, four incidents take place nearby the Mekelweg, Delft, the Netherlands.

- *Two cars collide*. A person “Jan” is calling 112 explaining that his car with license plate “SZ-VB-69” was hit by another car with plate “01-GBB-1” at corner of the Mekelweg and Stieltjesweg.
- *There is a wounded painter on a scaffolding*. A painter called “Drury” is calling 112 reporting that his colleague “Freek Drake” has fallen down from the scaffolding at Mekelweg 136.
- *A handbag is robbed*. A woman “Mary” reported that her handbag was robbed by a man riding a black motorbike in the left alley of the Mekelweg.
- *There is a confused old man*. Mr. Pieterese called the police for help to find his old father who got lost nearby the Mekelweg.

These four incidents constitute two scenarios, each with one main incident at its focus. These two scenarios are described in the following:

Car Collision Scenario. In this scenario a police unit is dispatched by the CCR to handle an incident of two collided cars at the corner of Mekelweg and Stieltjesweg. During the course of dealing with this incident, another police unit is located nearby to rescue a wounded painter and the ambulance is approaching. At almost the same time two other incidents also take place. The concrete activities of police officers can be explained according to four phases:

1. *Departure*. At 22:00, a police unit is requested to drive to the location of the car collision within 10 minutes.
2. *Arrival*. At 22:10, the police unit has arrived at the location of the car incident. Police officers in this unit start to take the initial actions, such as warning other drivers about the situation and managing the nearby traffic.
3. *Initial investigation*. At 22:15, police officers start to check the insurance papers and the official car papers. They also administer a breathalyzer test.
4. *Further investigation*. Some suspect substances are found in the car “01-GBB-1”. Policemen report this to the CCR at 22:25, and they use chemical sensing equipment to inspect the car.

Fallen Painter Scenario. In this scenario a local police unit is dispatched to handle an incident concerning a wounded painter. It is important to note that there is a traffic jam on the way because of an incident of two collided cars. The activities of this police unit in specific phases can be explained as:

1. *Departure*. At 22:02, a local police unit is dispatched to drive to Mekelweg 136 to rescue a wounded painter.

2. *Arrival*. At 22:08, police officers call the firebrigade to rescue the victim from the scaffolding, and they also start to manage the traffic to provide a free passage for the fire-engine.
3. *Initial investigate*. After ten minutes, the victim has been rescued and thus the situation is back to normal. Afterwards, police officers find a lot of strongly smelling paint disposed off between the trees. They report this new finding to the CCR and investigate the illegal dump of waste materials.
4. *Further investigation*. Another police unit located nearby for handling the car collision incident also finds some suspect chemical substances. Given the potential relation between these new findings, police officers continue to gather evidence.

3.4.2 Questionnaire Design

We designed two questionnaires with regard to the above car collision and fallen painter scenarios. Besides the description of the scenario, each questionnaire consists of twenty-five information items that might be relevant for the scenario.

Information Item	Phase	Item Rating			Reason for relevancy
		Don't need to know	Nice to know	Must know	
1. A witness reports a traffic jam in the Mekelweg because the collided cars block the road.	1.				
	2.				
	3.				
	4.				
2. The other car is owned by Kees Parker and has plate number 01-GBB-1, as reported by a witness.	1.				
	2.				
	3.				
	4.				
3. A witness reports that the driver in the car 01-GBB-1 tried to attack the other driver.	1.				
	2.				
	3.				
	4.				
4. Kees Parker has one record of drinking and driving 5 years ago.	1.				
	2.				
	3.				
	4.				
5. An accident with a painter happened at Mekelweg 136 and an ambulance is approaching.	1.				
	2.				
	3.				
	4.				
6. A woman's handbag is robbed by a man who rides a black motorbike in the left alley of the Mekelweg street, near the corner of the Pieter Calandweg.	1.				
	2.				
	3.				
	4.				
7. Jan Hudson has a record of holding illegal weapons.	1.				
	2.				
	3.				
	4.				

Figure 3.2: Example Questionnaire

Information Items. A list of information items is created in cooperation with domain experts and thus they are representative for the short notifications (i.e. messages) received by the responders from the dispatchers in the CCR. It is important to note that all information items are assumed to be delivered to users in all phases and thus each item has to be judged in the questionnaire on its relevance in four particular phases. Information items had to be judged with respect to a three-rating scale: (1) *must know*; (2) *nice to know*; or (3) *don't need to know*. A number of example information items are shown in Figure 3.2. These information items are either from real-time information sources including *emergency calls* and *police reports* or derived from standard information databases including *criminal record* databases. For example, under 1. we see in the figure a real-time report from a witness – "a traffic jam in the Mekelweg because the collided cars block the road"; under 7. we see that one criminal record concerning the targeted driver – "Jan Hudson has a record of holding illegal weapons".

We designed the questionnaire in such a way that every category is filled with a certain number of information items. In order to answer research question Q2, all information items are classified into nine information categories consisting of the five main categories with their subcategories. The information classification in two scenarios is shown in Figures 3.3 and 3.4.

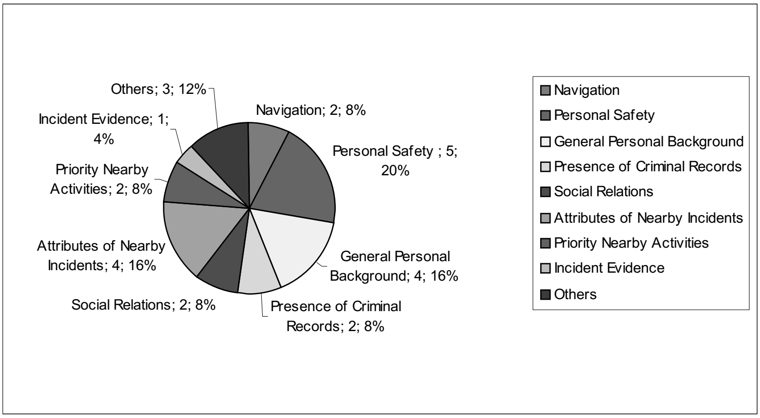

Figure 3.3: Information Classification in the Car Collision Scenario

Open Questions. Next to the questions asking for a relevance judgement for an information item, we also listed two open questions to collect other relevant information in the context of the scenarios at the end of the survey:

- **Open Question 1**: "Do you think the information items that you have rated from the list are enough to help your handling the incident?"
- **Open Question 2**: "Can you list other relevant items needed in the specific phases? For example, you can write down as: *in phase 1, I would like to know ..., because ....*"

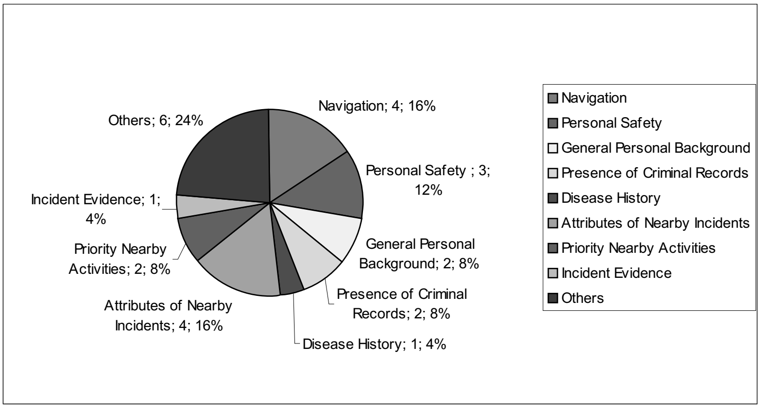

Figure 3.4: Information Classification in the Fallen Painter Scenario

3.4.3 Procedures for Completing the Questionnaire

The questionnaire-based study was conducted in the Multi Disciplinary Innovation Technology Center (M-DO-IT)[3] which is run by vtsPN and located at Driebergen in the Netherlands. This study involved four male experienced police officers. The average age of the participants is 46 years old and their average work experience within police organizations is 10 years. The main task of participants was to fill in two questionnaires by indicating which information item is relevant in which phase of handling the respective incident. A scene for answering the questionnaire is captured by Figure 3.5. The procedure consisted of the following steps:

Introduction. During the introduction, we informed the participants about the objectives of the study, its activities, planned duration and constraints. After making sure that all participants understood their role and task, we requested them to read the instruction. We also collected personal background information from the participants such as their name, e-mail address, age, gender, position in the organization and work experience. Besides, the participants were encouraged to provide an account of an experience learned from public safety work about wrong decisions being made by police officers due to the lack of critical information.

Round 1. In round 1, we handed out the first questionnaire which explains the car collision scenario to two of the participants, while giving the second questionnaire with the description of the fallen painter scenario to two other participants. Each participant also got a map in which the locations of all events are labeled. The participants were guided to step into the role of a police unit who is supposed to handle the respective incident. With reference to the four particular phases of a situation, the participants filled in the survey by indicating the relevance rating of each information item in a given phase. Also, the participants were asked to give their reasons for choosing the rating.

[3]http://m-do-it.ning.com/

Round 2. In the second round participants were required to deal with the other scenario. Similar to the first round, the participants was requested to judge the relevance of information items in given phases by indicating the relevance. They were also requested to list other relevant items by way of an open question.

Plenary Debriefing. The last stage of the process was the debriefing session. The participants were requested to comment on the process. In particular, they were asked to give the assessment criteria they considered and enumerate other relevant information.

Figure 3.5: A Scene of The Study

3.5 Relevance Rating Measurements

For each scenario, all participants provided the relevance ratings for twenty-five information items in four specific phases. In other words, each information item was judged by four users on its relevance in four phases. We averaged the relevance rating of each item from four users and further computed the standard deviation of the ratings. In order to derive general findings, we classified all information items into nine information categories as defined in Section 3.2, and analyzed the relevance of given types of information in four specific phases. We present the data measurements and results analysis in this section.

3.5.1 Methodology

The relevance judgements provided by four participants for fifty information items constructed from the two scenarios given in the four phases were measured.

Relevance Value Assignment. First of all, we specified a value for the relevance judgement of the participants according to a three-level relevance rating. Supposing that the value scale was defined from -1.0 to $+5.0$, each information item was assigned values according to its relevance judged by participants in four phases: "must know" was assigned a value of $+5.0$, "nice to know" was assigned $+2.0$, while "don't need to know" was assigned -1.0.

Average Measurement. The rating values for each item in the specific phase were summarized by the average (AVG) and the standard deviation (STD).

The standard deviation is defined as follows (N=4):

$$STD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Gold Standard Construction. According to the average estimated relevance values of all information items, a gold standard was constructed. As Figure 3.6 shows, since the rating value for the overall information items is between -1.0 and $+5.0$, the information items rated with no less than $+2.0$ (i.e. the average between -1.0 and $+5.0$) are considered as *relevant* while others are *irrelevant*. Specifically, since the value scale for the information items judged as relevant ("nice to know" or "must know") is between $+2.0$ and $+5.0$, the information items with a rating of no less than $+3.5$ (i.e. the average of $+2.0$ and $+5.0$) are considered as *highly relevant*.

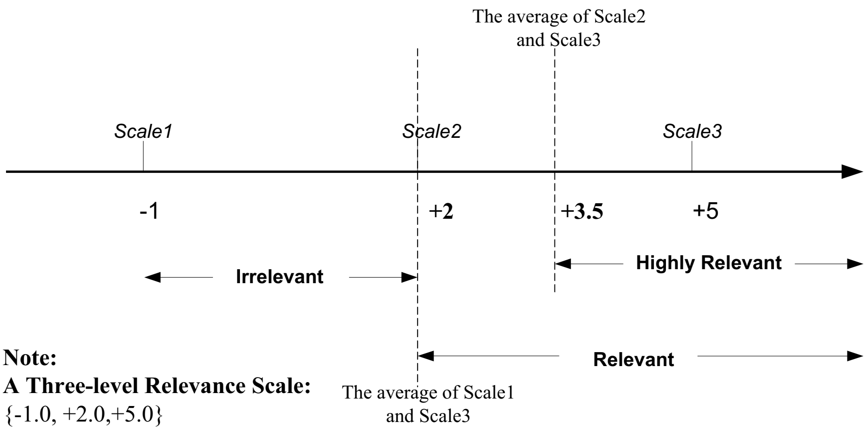

Figure 3.6: Gold Standard Construction

Relevance of Given Categories of Information Items. In order to determine the relevance of given categories of information in each phase, all information items were classified into nine categories as explained in Section 3.2. Then, we computed the average relevance value and also the standard deviation of all information items that were classified into a certain category.

3.5.2 Qualitative Results

The average relevance of a given type of information in all different phases is shown in Figures 3.7 and 3.8. Each diagram (diagram a to f) shows the average estimated relevance of all items in a given information category as well as the standard deviation of the relevance by means of an error bar. Figures 3.9 and 3.10 represent the relevance of all different

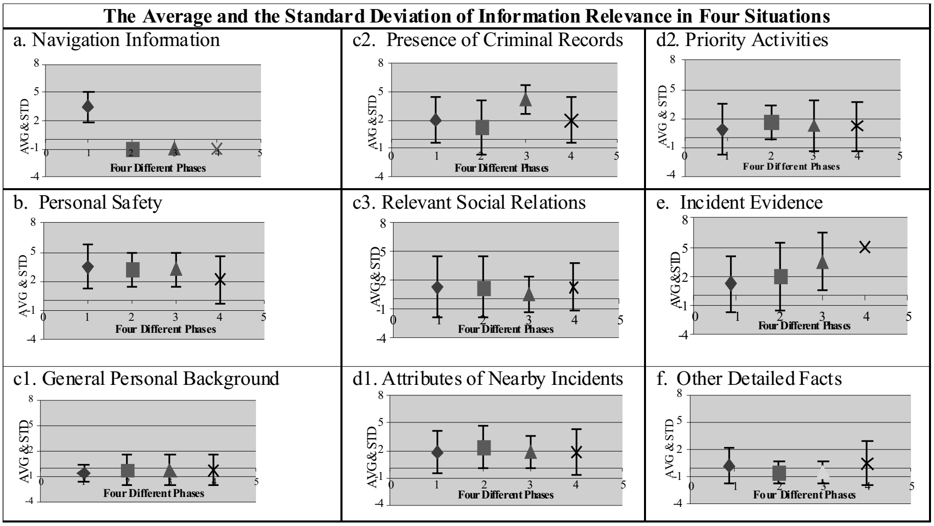

Figure 3.7: Relevance Measurement in the Car Collision Scenario

categories of information in a specific phase. The results provide answers for the three research questions we proposed.

Q1. Are information needs phase-specific?

We observed that users' information needs are highly specific for the given phase of the situation they are involved in. Among all eighteen diagrams (from "a" to "f") represented in Figures 3.7 and 3.8, eleven of them, i.e. diagram "a", "b", "c2", "d2", and "e" in the two figures ($5 \times 2 = 10$), and also diagram "d1" in Figure 3.7, show that for the information items that are in a particular information category the relevance ratings differ per phase. This finding indicates that the relevance of certain information items is clearly phase-dependent. Take diagram "e" in Figure 3.7 for example. It shows that although the incident evidence is *irrelevant* ($AVG < +2.0$) in phase 1 (Departure), such information is *highly relevant* ($AVG > +3.5$) in phase 4 (further investigation).

Q2. Do the different categories of information influence the information relevance within in a certain phase?

We found that for the specific phase of users are involved in, certain categories of information are more relevant than others. For each diagram in Figure 3.9 and 3.10, i.e. diagram I, II, III and IV, it can be clearly seen how the average relevance values for the different categories of information vary in each phase. For instance, in the phase of departure shown in diagram I, the relevance of *navigation information* and *personal safety* is the highest ($+3.5$), while the relevance of general personal background is the lowest (-1.0). Generally, in each phase the relevance of every category of information differs. This conveys indeed that police officers require different categories of information in a specific phase.

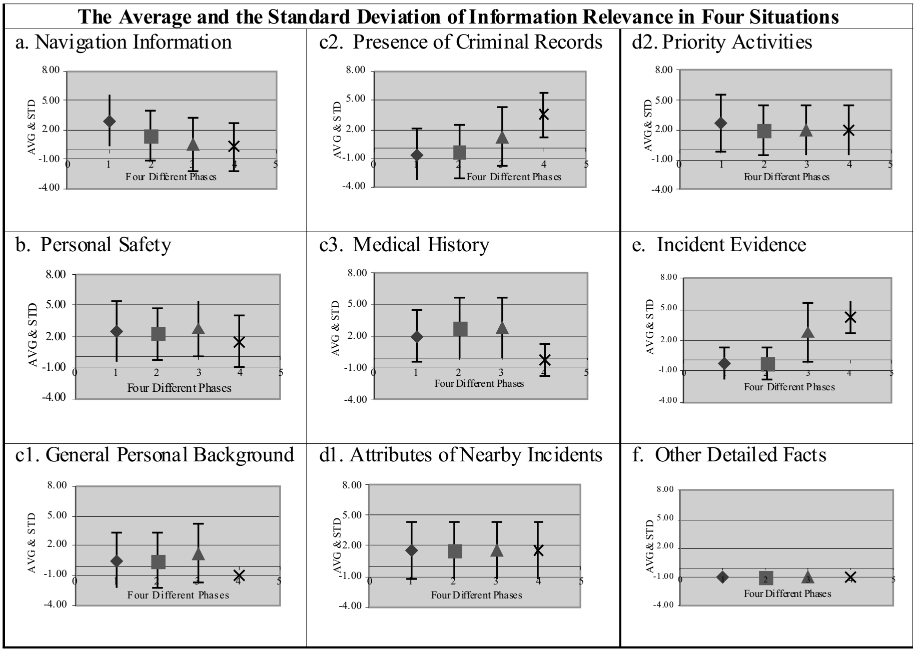

Figure 3.8: Relevance Measurement in the Fallen Painter Scenario

Q3. How can the relevance of information be predicted depending on the specific phase and category?

Given that the representativeness of our scenarios has been confirmed by domain experts, we can further derive the situation-specific information needs in the context of given scenarios from the two perspectives: information category and phase.

By investigating each category of information items in different phases, we can draw the following detailed conclusions from Figures 3.7 and 3.8.

1. As shown in diagram “a” in the two Figures 3.7 and 3.8, the navigation information is *highly relevant* when the users are in the phase of departure (phase 1), while it is irrelevant after they have arrived at the spot (phase 2, 3 and 4).

2. The personal safety information is relevant in all phases of handling an incident as diagrams “b” in Figures 3.7 and 3.8 show. The relevance in the phase of *further investigation* (phase 4) is relatively lower compared to other phases. By checking all the information items classified into this category, we found that if such information is reported in real time (e.g. aggressive actions of the driver in the car collision incident), then its relevance is higher than when it concerns static information (e.g. violence records of the driver).

3. The presence of criminal records is *highly relevant* when records may contribute to *initial investigating* and *further investigation* current illegal actions of involved persons, as shown in phase 3 of diagram “c2” (see Figure 3.7) and also in phase 4 of

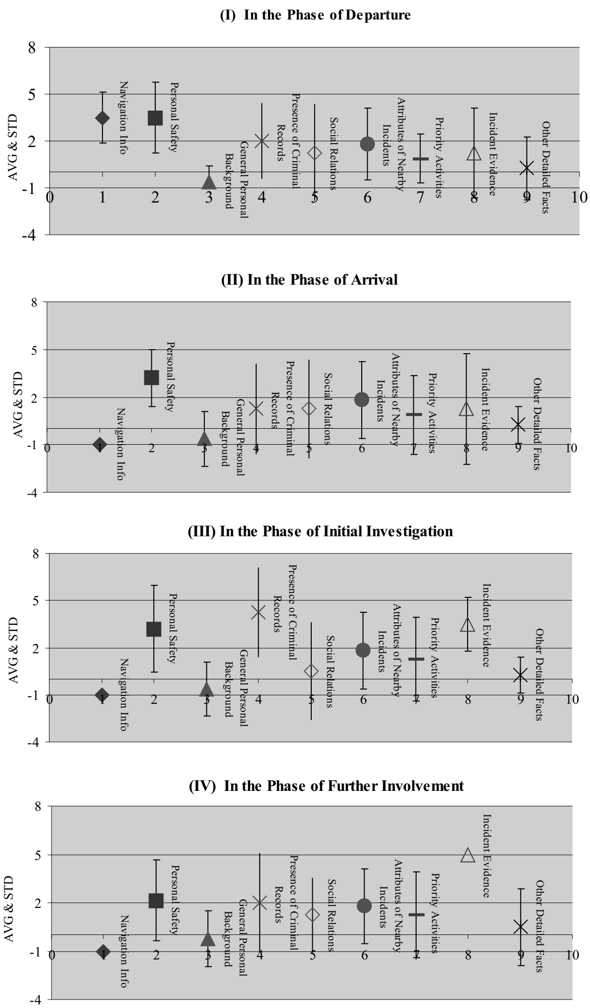

Figure 3.9: Information Relevance in Four Phases in the Car Collision Scenario

diagram "c2" (see Figure 3.8). Take one item concerning the "drunk driving records" for example; such information is *highly relevant* in the phase of *initial investigating* (phase 2) while it is *relevant* (phase 3) in the phase of *further investigation* (phase 4).

4. Although we assume that social relations are relevant when available evidence can hint at the fact that a closer investigation of the involved person is needed, the relevance rating (<2.0) represented in diagram "c3" in Figure 3.7 is not high enough to support this hypothesis.

5. The disease history of the targeted objects (see diagram "c3" in Figure 3.8) is *relevant* after *arrival* (phase 2 & 3) while it is *irrelevant* in phase 4.

6. Information about the nearby incidents is relevant when the police unit needs to keep

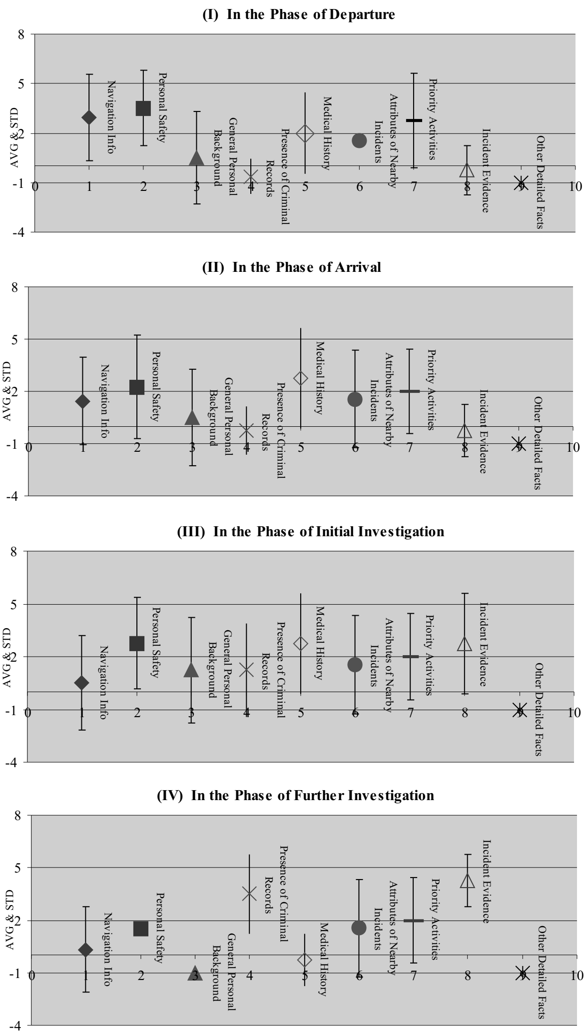

Figure 3.10: Information Relevance in Four Phases in the Fallen Painter Scenario

an eye open for providing useful information to nearby colleagues. Thus, in some sense, the relevance depends even more on the location than on the phase, which could explain the similar rating in different phases shown in diagram "d1" in Figure 3.7. Take a message reporting the escape direction of the robber for example; it is *relevant* to the police units who are nearby the robbery spot, although they are not handling this incident.

7. The relevance of nearby activities is higher after *arriving at the spot* shown in the diagram "d2" in Figure 3.7. While such information is *relevant* as shown in the fallen painter scenario (see Figure 3.8).

8. The evidence which may contribute to the explanation of an incident is *highly relevant*

in the phase of *further investigation* (phase 4), while it is *relevant* in the phase of *initial investigation* (phase 3). This finding is corroborated in the two scenarios as represented in diagram “e”.

In order to further investigate Q3, we summarized the requirements for different categories of information items in each phase as represented in Figures 3.9 and 3.10. We arrived at the following conclusions:

1. In the phase of departure in the two scenarios, the *highly relevant* information relates to the *navigation* and *personal safety*. The *relevant* information also relates to *criminal records* in the car collision scenario but it also relates to *medical history* as well as *priority activities* in the fallen painter scenario.

2. In the phase of arrival, the *relevant* information in the car collision scenario relates to the *personal safety* and *attributes of nearby incidents*. In the fallen painter scenario, it also concerns the *medical history* and *priority activities*.

3. In the phase of initial investigation, the *highly relevant* information in both scenarios relates to the *personal safety* and *incident evidence*; while the *relevant* information also relates to the *attributes of nearby incidents*. Specifically, the presence of *criminal records* is *highly relevant* in the car collision scenario; and the *medical history* is *highly relevant* in the fallen painter scenario.

4. In the phase of further investigation, the *highly relevant* information in both scenarios relates to the *incident evidence* and the *relevant* information also relates to the presence of *criminal records* and also *attributes of nearby incidents*. In particular, in the car collision scenario the relevance of *personal safety* information is higher while the presence of *criminal records* is lower compared to the fallen painter scenario. The *relevant* information in the fallen painter scenario also relates to the *priority activities*.

3.6 Agreement Measurements

As explained previously, in our experiment, four subjects provided their judgements for twenty-five information items with regard to their relevance in each of the two scenarios. In particular, the subjects judged the relevance of each information item in four different phases as “must know”, “nice to know” or “don’t need to know”. In order to evaluate whether the agreement on relevance judgements between the subjects is fair and thus to derive validate conclusions, we calculated the Fleiss’ kappa in specific phases in each scenario.

Fleiss’ kappa (Fleiss and Cohen, 1973) is a statistical measure for assessing the agreements between multiple raters when assigning categorical ratings to a fixed number of items. It can be interpreted as expressing the extent to which the observed amount of agreement among raters exceeds what would be expected if all raters made their ratings completely randomly. We give the Fleiss’ kappa statistic here to assess the agreements between the users who judged the twenty-five items with respect to their relevance in a specific phase.

Definition. N is defined as the total number of items, n is the number of ratings per item, and k is the number of categories into which assignments are made. The items are indexed by $i = 1, \dots N$ and the categories are indexed by $j = 1, \dots k$. Also, n_{ij} represents the number of raters who assigned the i-th item to the j-th category. Then, the kappa, k, can be defined as:

$$k = \frac{\overline{P} - \overline{P}_e}{1 - \overline{P}_e} \tag{3.1}$$

$$\overline{P} = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{n(n-1)} (\sum_{j=1}^{k} n_{ij}(n_{ij} - 1) \tag{3.2}$$

$$\overline{P}_e = \sum_{j=1}^{k} (\frac{1}{Nn} \sum_{i=1}^{N} n_{ij})^2 \tag{3.3}$$

The value of k is interpreted as follows (Landis and Koch, 1977): if the raters are in almost *perfect agreement* then $0.81 \geq k \leq 1.00$; if they are in *substantial agreement* then $0.61 \geq k \leq 0.80$; if they are in *moderate agreement* then $0.41 \geq k \leq 0.60$; if there is *fair agreement* then $0.21 \geq k \leq 0.40$; if only *slight agreement* then $0.0 \geq k \leq 0.20$; and if *poor agreement* then $k \leq 0$.

Calculation. In our case, we have four users ($n = 4$) who judged the relevance of twenty-five information items ($N = 25$) as “must know”, “nice to know” or “don’t need know”. To maximize the chance of agreements between users, we consider both the judgements of “must know”, “nice to know” as a positive answer (*relevant*) while the judgements of “don’t need to know” as a negative answer (*irrelevant*) from subjects. Thus, the judgements from subjects are classified into two categories (k=2): “relevant” or “irrelevant”. For each scenario, all users provided their judgements on the relevance of certain “items” in four different phases. Accordingly, we measured the degree of agreement corresponding to the specific phases per scenario.

Results. The values of the Fleiss’ kappa constructed from the two scenarios are summarized in Table 3.1. According to the interpretation of k values (Landis and Koch, 1977), the users achieve *moderate agreement* (k=0.43) in the phase of *initial investigation* in the car collision scenario. In the fallen painter scenario, the users only achieve *slight agreement* in the phase of *initial investigation* (k=0.16) and *further investigation* (k=0.17). In other cases, the users achieve *fair agreement* given the k value ranging from 0.23 to 0.33. The main reason for explaining the relatively low degree of user agreement in the fallen painter scenario is that there is a user who always held a different opinion with others. If we don’t take into account the judgements from this user, then the fair agreement is achieved among the rest of three users, given that the kappa value is increased in each phase. These increased values in four phases are listed as: k=0.36, k=0.26, k=0.25, k=0.39.

Phases	Departure	Arrival	Initial Investigation	Further Investigation
k in the Car Collision Scenario	0.26	0.32	0.43	0.23
k in the Fallen Painter Scenario	0.23	0.16	0.17	0.33

Table 3.1: Fleiss' Kappa in the Two Scenarios

3.7 Conclusion

In this chapter we have reported on a study with the goal of getting to know the information needs of police officers. The notion of "phase", in a broad sense, can be defined as a period in which responders are engaged in some logical part of a task following the incident response procedure. In the context of our scenarios, we specified four phases that police officers are in. According to typical types of information provided from the domain experts, we classified those information police officers often deal with into a set of information categories. Those nine categories of information we built are representative as they were derived from the CAP data structure.

The analysis results mainly shed light on the situation-specific information needs of police officers in certain scenarios. The observations from our user study have clearly answered the three research questions we posed and thus help us to generalize the typical information needs of police officers in particular phases. We concluded that:

- The information needs of police officers are highly specific for the given phases in which they are involved.
- When a police officer is in a particular phase, certain categories of information are more relevant than others.
- We identified which categories of information police officers require in which phase.

However, one clear limitation is that the number of participants is relatively small – we could only enroll four police officers involved in this study, which results in the relatively low degree of user agreement. Nevertheless, after consultation of police experts, we are confident that the scenarios defined are realistic and representative and thus the results measured based on those reasonable data are probably generalizable for other situations.

In the next chapter we focus on discussing the design of an architecture for contextualized information delivery on the basis of the information needs defined here.

Part III

Architecture Design

Chapter 4

Design Considerations and Global Architecture

In the previous chapter, we have reported a study with the goal of representing the information needs of end-users on the basis of given scenarios. In this chapter we derive the requirements for the architecture design from that study. Following these requirements, we materialize our design considerations in terms of information models and the workflow of the relevance assessment. Then, we present the Contextualized Information Delivery Architecture (CIDA). The main components of CIDA consist of (1) a situational data (i.e. context data) repository; (2) an information item repository; (3) a rule store; and (4) a rule engine.

This chapter is structured as follows. We start by stating the requirements for the architecture design in Section 4.1. Then, we discuss an ontology-based information model in Section 4.2 and a rule-based approach for the relevance assessment in Section 4.3. Lastly, we present the architecture and explain the main function of each component in Section 4.4.

4.1 Requirements

The results from the study with police officers presented in Chapter 3 guide the development of an architecture supports the delivery of relevant information specific for users' contextual situations. We derived the requirements according to our observations from the study as follows:

- The finding that the information needs are highly specific for the phase end-users are in, yields a crucial requirement: the architecture should consist of a component that can represent dynamic aspects of a user's situation, such as the task at hand, the events that happen and current phase.
- The finding that certain categories of information are more relevant than others within a specific phase generates a requirement: the architecture should include a component that is able to integrate and exploit different categories of information. That information could come from either dynamic message sources, such as sensors, or static background information sources, like criminal records.

- Another finding is that certain categories of information are more relevant for police officers than others within a specific phase. Following this finding, the system should be able to cope with different categories of information.
- The results that identify which categories of information end-users require in which phase leads to the following requirement: the architecture should support the development of systems which can determine the relevance of information given a user's context.

Many researchers have attempted to provide architectural support for the development of context-aware applications. There are the middlewares that provide support for gathering, processing and interpreting the context information such as SOCAM (Gu et al., 2004); the network infrastructures for providing context-ware computing (Castelli et al., 2007); and also the toolkits that support intelligibility and control in end-users' applications (Dey and Newberger, 2009; Kawsar et al., 2010; Lim and Dey, 2010). However, some of them are too depended on their application domains. Let us consider an abstraction component called *Situation* (Dey and Newberger, 2009), which was architected to extend an existing infrastructure *Context Toolkit* (Dey et al., 2001). Although this extended architecture has been applied to the implementation of a museum guide and a living room controller, it does not address how applications can react to changes in outdoor activities of mobile users. Moreover, most of the existing architectures, such as SOCAM, focus on acquiring, interpreting and discovering the context, but they do not tackle the challenge of assessing the relevance of information in given a context. With the goal of tackling these challenges, the design of CIDA is constructed to address the above requirements for contextualized information delivery.

4.2 Information Modelling

In this section, we discuss our design considerations with respect to information modelling.

4.2.1 Ontologies and Ontology-based Context Model

Ontologies. The term *ontology*, originating from the philosophical discipline, refers to the basic description of things in the world. It has been adopted by the computer and information scientists. Several ontology definitions are provided from different perspectives. One of the most popular definitions was given by (Gruber, 1993); later, (Studer et al., 1998) enriched this definition (see Chapter 2). These views consider an ontology as a *domain model* that should create a *shared* understanding of certain concepts as well as relationships between these concepts. (Cimiano et al., 2010) further explained that: "*The essential purpose of an ontology is to encode knowledge about a certain reality in a declarative way, independently of any application and the way this knowledge might be used, such that somebody can reuse this knowledge and apply it in their own context*."

Ontology-based Context Modeling. An efficient model for storing, representing and sharing context data in a machine-readable formalism is essential for developing a context-aware system. Therefore, many researchers have been working on modelling of context information relying on various approaches. (Strang and Linnhoff-Popien, 2004) enumerated the most relevant context modelling approaches as: (1) key-value models; (2) markup scheme models; (3) graphical models; (4) object oriented models; (5) logic-based models; and (6) ontology-based models. The evaluation of these different approaches showed that ontologies are the most expressive models. Because ontology-based context modelling has advantages in terms of sharing a common understanding of the structure of context information among users, devices as well as services, and reusing as well as analyzing of the domain knowledge, and also describing contexts at a semantic level (Cimiano et al., 2010; Gu et al., 2004).

In order to address the requirement for modelling dynamic aspects of a user's situation, we designed an ontology-based context model which represents the current contextual situation of mobile users who are engaged in handling a certain event. Our context model consists of a generic ontology and a domain-specific ontology. Specifically, the generic ontology for representing the basic concepts is extensible to different domains; the domain-specific ontology that defines the details of general concepts and their properties is specialized for the domain of mobile police work.

4.2.2 RDF Data Model and Schema

The interpretation of each RDF statement is that: a subject *S* has property *P* with value *O*, where *S* and *P* are resource URIs (Uniform Resource Identifier) and *O* is either a URI or a literal value. RDFS extends RDF in the sense of supporting the *Class* and *subClass* relations, as well as providing domain and range mechanisms for describing properties. While RDF only defines a simple data model for expressing statements using triples, RDFS provides a framework for a particular vocabulary that defines the properties and data types that are meaningful for the application at hand. Together, RDF and RDFS provide a semantic structure for defining machine-processable ontologies and metadata structure (Jacob, 2003).

In the design of CIDA, we relied on the RDF data model and schema to formalize all available information from different sources for several reasons:

1. **Ease of data integration**. The RDF data model facilitates the integration of multiple data sources.

   RDF relies on the notion of URI as an unique identifier to point to resources, which enables meaningful composition of data from different information sources regardless of format or serialization. Different URIs can represent the same entity. RDF allows us to identify resources and to link distributed data from various sources together, including unstructured (e.g. texts or recordings of emergency calls), semi-structured (e.g. HTML documents or template-based forms filled by dispatchers in the CCR), and structured sources (e.g. rational databases for personal background information).

2. **Expressivity and Flexibility**. RDF is a simple but expressive data model, which allows us to create expressive vocabularies with RDF schema to specify the concepts and their interrelationships at a semantic level in a flexible way.

   RDF allows us to define our own vocabularies to describe the logical relations between data structures without being restricted to hierarchal (i.e. child/parent) or attribute relations. Hence, by defining new types and predicates, we are able to create more expressive vocabularies with exact semantics within RDF schema.

Different to a hierarchical tree structure as we know it from XML, RDF provides a flexible schema since its statement is a directed labeled graph. Compared to the entity-relationship model where the entities, their attributes and relationships to other entities are strictly defined, RDF has an advantage because of its schema-free structure (Sakr and Al-Naymat, 2010). In particular, any object from one RDF triple can be a subject of another triple. For example, we create the predicate *hasRating* for the object Message and the corresponding statement is: “*_:Msg _:hasRating _:Rat*.” Further, the Rating can also be an Object with its two predicates: *isForUser* and *hasValue*. The two corresponding statements are: “*_:Rat _:isForUser _:User ; _:Rat _:hasValue _:Val*.” By these statements, the relevance of a given message for a specific user with a certain value can be represented.

3. **Extensibility**. RDF schema supports the incorporation of new relations/properites without any change to existing data structures.

   An important advantage of RDF is its extensibility in both schema and instance level (Angles and Gutierrez, 2005). RDF differs from object oriented data models in that instead of defining a class in terms of the properties its instances may have, an RDF schema will define properties in terms of the classes of resource to which they apply[1]. For instance, we could define the *isEngagedIn* property which has as domain User and as range Task; with such an RDF property-centric approach it is then easy for us to add a new predicate *isTargetedAt* with as domain User and as range Event without the need to re-define the User class. In addition, compared to the rigid and fragile schema of the relational model which is directed to simple record-type data with a structure known in advance, RDF has an advantage in that it supports the extension of the structure by the simplicity of adding new relations/properties while preserving the existing structure. Hence, new information can be added incrementally as system functions evolve, which fits well with the modern notion of data management and its pay-as-you-go philosophy (Jeffery et al., 2008).

4. **Inference**. RDF has a formal semantics which provides a sound basis for reasoning about the meaning of an RDF expression. In particular, it supports rigorously defined notions of entailment which provide a basis for defining reliable rules of inference in RDF data[2]. The RDF schema specification includes features which require basic inferencing facilities in the storage/query system[3]. For example, the *rdfs:subClassOf* and *rdfs:subPropertyOf* predicates are transitive. RDF schema can be further extended with a “logic layer” for supporting dynamic rule-based inference beyond mere inferring static facts (Bozsak et al., 2002; Ianni et al., 2009). We could use inference rules to derive new facts or new relationships based on the exiting data in our future work.

[1] http://www.w3.org/TR/rdf-schema/
[2] http://www.w3.org/TR/2004/REC-rdf-concepts-20040210/#section-formal-semantics
[3] http://www.w3.org/TandS/QL/QL98/pp/queryservice.html

4.3 Rule-based Approach for the Relevance Assessment

In order to address the requirement that an architecture should support the development of systems which can determine the relevance of information given a user's context, we used a rule-based approach for fulfilling the core functionality of the relevance assessment. Our design considerations at this point are explained as follow:

1. **Rule-based architectures support the adaptability of applications**. Context-aware applications should continuously monitor the users' environment in order to detect changes and react to them. In this avenue, rule-based architectures offer flexibility with respect to tackling the dynamicity of environment and support the reconfiguration of systems according to changing needs without the requiring any reprogramming. As an evaluation of an implementation in the domain of healthcare shows, a rule-based approach is suitable for highly dynamic context-aware services (Dockhorn Costa et al., 2008).

2. **Rule-based architecture allow users to specify the behavior of applications directly and easily**. Because rules are easy to adapt, alter and maintain, this feature makes them an attractive solution for non-expert users (Bikakis and Antoniou, 2010). The users is able to directly define as well as modify the rules that specify the behavior of a system in a given situation. For example, context-aware behaviors could be specified by a rich set of business rules (Xu et al., 2008). In addition, the use of rules on top of ontologies can enable adaptive functionality that is both transparent and controllable for users (Tran et al., 2008). Also, different association-rules mining techniques are available to discover patterns of the form *context* $\Longrightarrow$ *activities*, which expresses the fact that a user in a particular context is likely to perform an activity (Mejia et al., 2010). These techniques enable us to explicit represent which phase a user is current in based on physical contexts.

4.4 Global Architecture

The requirements derived from the study have guided the design of an architecture and helped to define the functionality of single components. CIDA was thus designed for contextualized information delivery. The main function of each component in CIDA is explained below:

- **Information Item Repository**. It stores all information items, which are either from dynamic information sources including sensors or from static background information (e.g. a database of criminal records). The available information items in CIDA can be essentially regarded as small information containers consisting of facts (formalized in RDF) originating from different information resources. The input information from different sources is firstly assigned to certain categories and represented in an information item model. Then, all these representations are stored in the information item repository in order to assess their relevance.

- **Situational Data Repository**. The situational data repository stores three types of context information, including the *sensed context* gathered from sensors and observers, the *manually entered context* specified by end-users, such as the input by

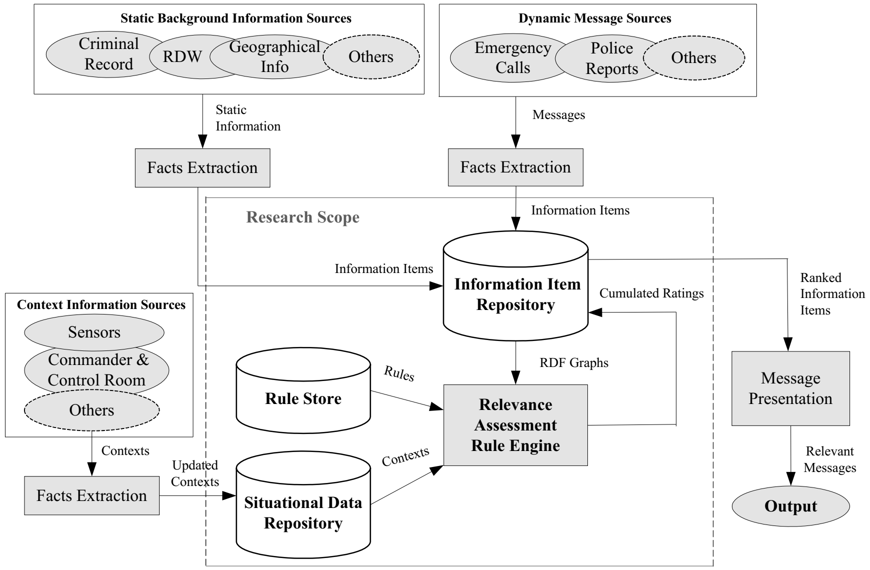

Figure 4.1: The Contextualized Information Delivery Architecture

police officers on their mobile devices, and the *deduced context* derived from the above two types of context information and also from available databases. All context information is formalized in an ontology-based context model that will be presented in Chapter 5.

- **Rule Store**. It contains a set of rules which specifies how the relevance of information items for certain users is updated when a list of conditions is fulfilled. Our rule language will be described in detail in Chapter 6.

- **Relevance Assessment Rule Engine (RARE)**. RARE fulfills the core functionality of assessing the relevance of information items by executing the rules in the *Rule Store* while taking into account the context information in the *Situational Data Repository*. The relevance ratings of information items are collected and updated according to the accumulated values generated by the rule engine. The design and implementation of this component will be explained in detail in Chapter 7.

An overview of how CIDA works is provided in Figure 4.1. All information items which contain the facts about events, objects and background information are stored in the *Information Item Repository*. All context information captured by various sources is also formalized according to the RDF data model and is stored in the *Situational Data Repository*. Once the context is updated or a new information item is received, the *Rule Engine* is triggered to execute all rules in the *Rule Store* in order to assess the relevance of information items in the context. The ratings of all executed rules are aggregated to yield cumulated ratings. Then, the rating values of information items, which are stored in the *Information Item Repository*, are updated for each user according to the cumulated ratings. The information items with the highest cumulated ratings are presented by the *Message Presentation* component according to some specified presentation strategy. This component is part of the overall system but is beyond the scope of this thesis and will be considered in future work.

CIDA has two crucial features. One is the representation of the dynamicity of environments relying on an ontology-based context model, in particular the description of mobile users' activities in a given situation. Another one is the flexibility of adaptation, which builds on declarative rules specifying which types of information to deliver in which contexts. These rules can be modified independently of the codes executing them, thus providing a principled manner to adapt the behavior of applications to different domains without requiring any reprogramming.

4.5 Conclusion

Guided by the requirements from the study in Chapter 3, we have discussed our design considerations and presented CIDA. In order to support applications to tailor their behavior to the specific needs of mobile users acting in a given context, CIDA was designed to have an ontology-based context model that can represent the current contextual situation of mobile users. To integrate and exploit information from multiple data sources, CIDA comprises an information item model relying on RDF. With the goal of fulfilling the core functionality of the relevance assessment, CIDA includes a rule engine responsible for determining the relevance of information items given a user's context. The main strength of CIDA lies in its support for adaptation of applications to different situations and domains by the mere addition or modification of rules.

In the next chapter, we will present how the various sources of information are modeled using ontologies. In particular, we focus on establishing an ontology-based context model.

Chapter 5

Information Model

In the context of CIDA presented in Chapter 4, we illustrate how to formalize various sources of information relying on the RDF data model in this chapter. In particular, we establish an ontology-based context model, which characterizes the contextual situations of mobile users who are engaged in handling a certain event.

5.1 Information Sources

In this section, we introduce the available information sources in the case that applying CIDA in the domain of mobile police work.

5.1.1 Information Item Sources

The information items – either coming from the dynamic information sources or the background information sources – will be assessed by CIDA with respect to their relevance. In our application domain, we refer to available information items simply as "messages" as they constitute potentially relevant condensed notifications to be provided to police officers on their mobile devices. The sources of information items in our case consist of:

1. **Emergency Calls**: messages coming from emergency calls that report the ongoing events. Emergency calls are recorded by the dispatchers in the CCR, who are responsible for dispatching the information to police officers who are executing their tasks.

2. **Police Reports**: oral communication between police officers and CCR. In the Netherlands, the communication channel for the oral communication between police officers and the CCR is provided by the C2000 mobile digital communication system[1].

3. **Background information**: background information contained in standard information systems, such as criminal record databases, or the RDW (Rijksdienst voor het Wegverkeer, the Dutch road traffic department) databases which contain license plate and owner information about all registered Dutch cars (Feenstra et al., 2006).

[1] www.c2000.nl

5.1.2 Context Data Sources

The context data – collected partially automatically from sensors/systems and partially updated by the CCR – is also assumed to be stored in the context of CIDA. Context data essentially provides information about the current contextual situation of police officers, in particular about their tasks and targets in a given phase, but it could also include data from sensors. In our case, the available sources for capturing the context data consist of the following systems which are assumed to be connected to the central police systems.

1. **The GMS system** (Gemeenschappelijk Meldkamer Systeem, Common Communications Centre System). The GMS is a common emergency room information system. This system has many functions. In the first place it functions as a plotting screen which displays every police unit logged in. It also has a database function for procedures and phone numbers necessary for correctly executing police work and it links to the C2000 system and the CityGIS (GPS) system. Moreover, the GMS system recognizes keywords and phrases such as "burglary" or "collision" and will automatically initiate the accompanying procedures and intake or dispatch scripts (Groenewegen and Wagenaar, 2006).
2. **The AVLS system** (Automatic Vehicle Location System). It is a geographic positioning system giving location information of the police units. This system can enhance communication by putting terminals in police cars (Redmond and Baveja, 2002).
3. **Other sensors**. For instance, the RFID (Radio Frequency Identification) system is a technology that has revolutionized automatic identification and data capture technologies. It can be used to identify and track the involved people and cars. Also, the chemical sensing equipments for inspecting suspect substances.

5.2 Information Item Model

An unified information item model – illustrated in Figure 5.1 – allows us to integrate dynamic as well as static information.

The RDF data model is expressed using directed labelled graphs (or "nodes" and "arcs" diagrams). In this chapter we use the general notation for the RDF model[2]: a node (ellipse in the figures) for a resource; an arc for a predicate; and a rectangle for a value. Specifically, we use different symbols to distinguish between the object property and the subject property. We also label a class and its sub-classes. In addition, the plus symbol represents that the corresponding predicate could have multiple values.

The information item model has generality in the sense that it represents facts along seven dimensions corresponding to the so-called *Seven WH-questions* – what, where, when, who, with what, how, and why (Erteschik-Shir, 1986). The facts capture information about the event taking place (what and why), its location (where it happened) and time (when), the object involved (who, with what and how) as well as the type of information (and thus partially specifying the why- and how-dimensions), and the information source (where it comes from). For this purpose, we built a set of (potentially overlapping) information categories partially derived from a set of reference categories developed in the Netherlands

[2]http://www.w3.org/TR/rdf-syntax/

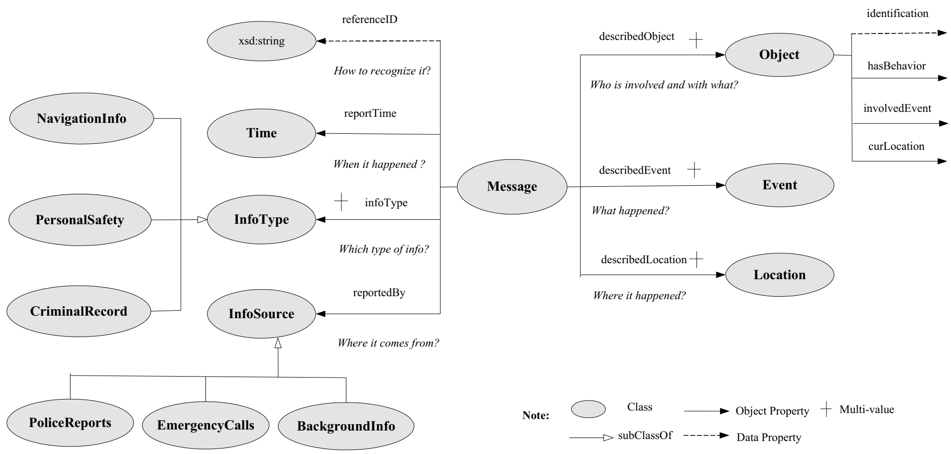

Figure 5.1: Information Item Model

(ACIR, 2005) and the structure of the Common Altering Protocol (CAP)[3]. In particular, we reused the information categories related to navigation, safety, activity, object and targeted events as well as other events. We introduced subcategories corresponding to the Object category relevant for the car collision scenario as well as the fallen painter scenario, such as *criminal record*, *social relation* and *medical history*, and a subcategory of *evidence* that was derived from the Activity category.

Furthermore, as Figure 5.2 shows, the information item model allows the representation of the relevance of a given information item for a specific user via a rating object (*relevance*) with its properties *isForUser* and *hasValue*. Note that one information item could have different rating values for users involved in different contextual situations.

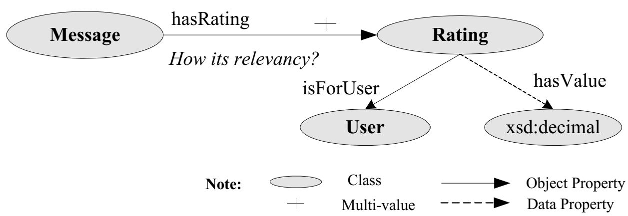

Figure 5.2: Rating Object in the Information Item Model

To illustrate how information items are formalized using the RDF model, let us consider a message reporting the aggressive behavior of a driver. As Figure 5.3 shows:

- The corresponding message “AggressiveActionMsg” is of type personal safety information (*infoType*). Its identification (*reference ID*) is “aggrActionMsg1”.

- It describes a driver named “Bob” (*describedObject* and *identification*). It further represents that the driver “Bob” is involved in a car collision event (*involvedEvent*) and has aggressive behavior (*hasBehaviour*).

[3] http://docs.oasis-open.org/emergency/cap/v1.2/pr03/CAP-v1.2-PR03.pdf

- This message is reported by a witness (InfoSource) at “12:00” (*reportTime*).

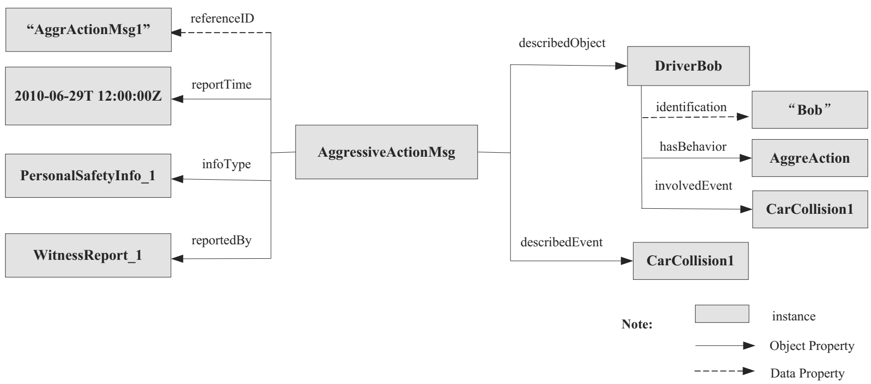

Figure 5.3: An Information Item

5.3 Ontology-based Context Model

In this section, we describe an ontology-based context model by starting with our definition of context and a simple scenario.

5.3.1 Context Definition

Our working definition of context is based on the most frequently cited definition given by (Dey and Abowd, 1999) (see Chapter 1). Consider that the main functionality of our system is to assess the relevance of information by understanding the contextual situation of mobile users. By context we refer to *any attribute, e.g. role, task, time, location, targeted event and involved objects, which characterizes the situation of mobile users for the purpose of assessing the relevance of information.* According to the way of obtaining context information, we classify contexts into three main types – sensed context, manually entered context, and deduced context.

1. Sensed context. It is obtained from physical sensors or observers, e.g. the location of police units and the location of events from the CityGIS system.

2. Manually entered context. For instance, the procedure of a routine task which could be predefined by the operators in the CCR and police officers could be informed it via C2000 system. Also, the status or the specific phase of a situation which could be specified and updated by police officers themselves via mobile devices.

3. Deduced context. It is derived or inferred from interpreting the low-level context (i.e. sensed or manually entered context), such as the current activities.

   Different types of contexts have different temporal characteristics (Gu et al., 2005). The sensed context may vary in a few seconds when a user moves, but the other two types of context usually extend over a certain time period. Note that some context could be captured in different ways. Take the *phase* for example, it could be specified by police officers themselves (manually entered), and also could be derived from information about the type of activity.

5.3.2 Example Scenario

In order to illustrate how our context model incorporates the special requirements of end-users, we introduce a simple scenario here concerned with a police officer who is dealing with a car collision incident.

A police officer "Jan", who is located at Mekelweg street, where a car collision incident has happened, is engaged in dealing with this urgent incident. At "12:00", he begins to investigate the involved drivers by starting with an alcohol breathalyzer test following the routine procedures. In the phase of initial investigation, he meets some troubles since one of the drivers is very aggressive. After controlling the situation, he continues to investigate the incident at "12:20". The main task is the evidence collection, including the interviewing of the witnesses.

Lessons Learned from the Scenario. From the above example, we can see some typical characteristics of context information exhibited in the working environments of mobile police officers as:

1. The situation of police officers can be mainly described by the following dimensions of context information, including the time and location (sensed context), event (sensed and deduced context), targeted objects (sensed and manually entered context) and task (manually entered and deduced context).

2. There are relationships between the context elements. As the above scenario shows, (1) a user is related to a certain location – police officer "Jan" *is located at* "Mekelweg"; (2) a user is related to a certain task – police officer "Jan" *is engaged in* the task of dealing with a car collision incident; (3) an event is related to a task – a car collision incident *is targeted by* police officer "Jan"; specifically, (4) a user is involved in a specific phase within the scenario at a certain time – police officer "Jan" is *in phase of* the initial investigation between 12:00 and 12:20; afterwards, he is *in phase of* further investigation.

3. The situation police officers might encounter while executing tasks has different emergency levels. For instance, while a police officer "Jan" is administering a breathalyzer test for a driver, he might get into an urgent situation caused by the aggressive behavior of that driver.

We can summarize from the above example that how to extend the basic context concepts in order to meet the specific requirements in the domain of mobile police work. In general, to represent the current contextual situation of mobile users who are engaged in handling a certain event, a context model should describe four dimensions of users' contexts, i.e. time, location, event, and task. Moreover, it should reveal the relationships between these dimensions at a semantic level. For instance, the relation of *which event is targeted by which user* should be represented. Specifically, according to the characteristics of this working environment of police officers, a context model should also represent: (1) the specific phase of a police officer is in; (2) the objects targeted by a police officer; and (3) the emergency level of an event.

5.3.3 Context Model

Existing context models usually enumerate domain-specific concepts, such as a user's preference, device or location, which can be eventually considered as contexts in that domain. However, those context elements are structured without taking into account their relationships to the context dynamics (Vieira et al., 2011). Compared to the current context models – most of them considering spatial and temporal dimensions, the essential difference of our ontology-based context model is that it incorporates both the type of task that users are engaged in and a certain event that users are dealing with. Moreover, it represents the relationships between the dimensions of context information in order to characterize the contextual situations of mobile users. Our context model consists of a generic ontology and a domain-specific ontology as explained in the following:

A Generic Ontology. A generic context ontology represents the high level concepts of current situation of mobile users. As shown in Figure 5.4, the generic ontology defines the basic context concepts of user, time, location, event, and task.

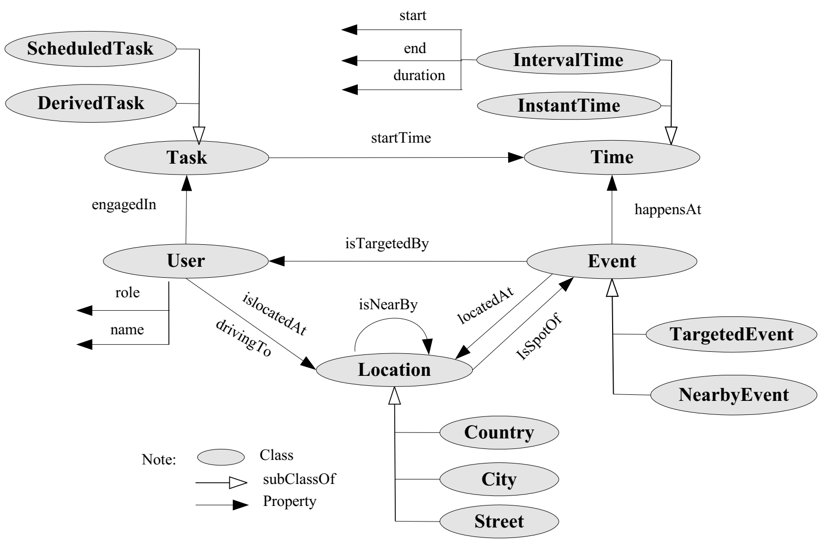

Figure 5.4: A Generic Context Ontology

Our context model is based on the four primary context types, viz. identity, location, activity and time, defined by (Dey et al., 2001), and an upper ontology for situation awareness provided by (Matheus et al., 2005), which contains the *EventNotice* class for describing events in a real-world situation and indicating changes in the situation. The generic ontology in our context model thus describes the relevant aspects of a situation which a mobile user is involved in, and it is reusable and extensible in different domains.

The relationships between context dimensions are represented in the context model by the predicates. For example, the *isTargetedBy* predicate, which has as domain Event and as range User, reveals the relation between an event and a user representing which event is targeted by which user; the *engagedIn* predicate, which has as domain User and as range Task, reveals that relation between a user and a task representing which user is engaged in which task; the *isLocatedAt* predicate, which has as domain User and as range Location, reveals the relation between a user and a location representing where a user is located; and the *happensAt* predicate, which has as domain Event and as range Time, represents when an event happens.

A Domain-specific Ontology. Our context model was designed to be extended to meet the domain-specific needs. The domain-specific ontology describes details of general concepts in the generic ontology and their properties in the domain of mobile police work. The domain-specific ontology creates a subclass of the User class to define the role of police officers, and the properties of the Event class to describe the objects involved in an event as well as an emergency level of an event. In addition, the User class was extended to have the property *inPhaseOf*, which specifies a specific period police officers are involved in, described by the four subclasses of the Phase class. It can be seen from Figure 5.5 that:

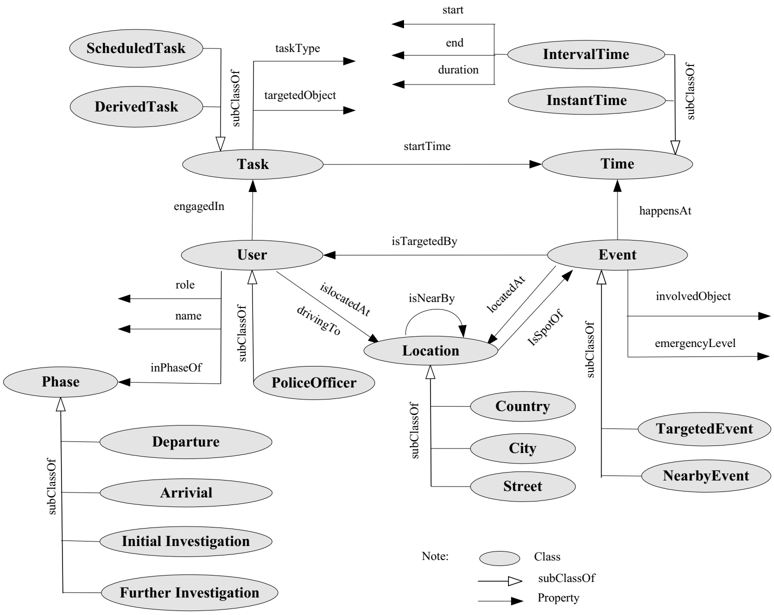

Figure 5.5: Domain-specific Context Ontology

- The **User** class has a subclass named PoliceOfficer. The **User** class is extended to describe the *phase* of police officers.
- The **Event** class has the predicates: *involvedObject*, and *emergencyLevel*. This class is extended to describe who is involved, what has been happened nearby, and what is the emergency level.

- The **Task** class has subclasses such as ScheduledTask and DerivedTask in the generic ontology. In order to represent the targeted objects and the type of task, it is extended to have these two predicates: *targetedObject* and *taskType*.

- The **Location** class has subclasses such as Country, City and Street in the generic ontology. It is employed to represent where an event has happened (*isSpotOf*) and where a user is located (*locatedAt*). It also has the predicate *isNearby* to describe a particular spatial relation.

- The **Time** class is employed to record when an event has happened, when a task has started (InstantTime), and how long an event or task has been taken (IntervalTime).

Turning back to the scenario describing a contextual situation of a police officer "Jan", his situation can be represented according to our context model as Figure 5.6 shows:

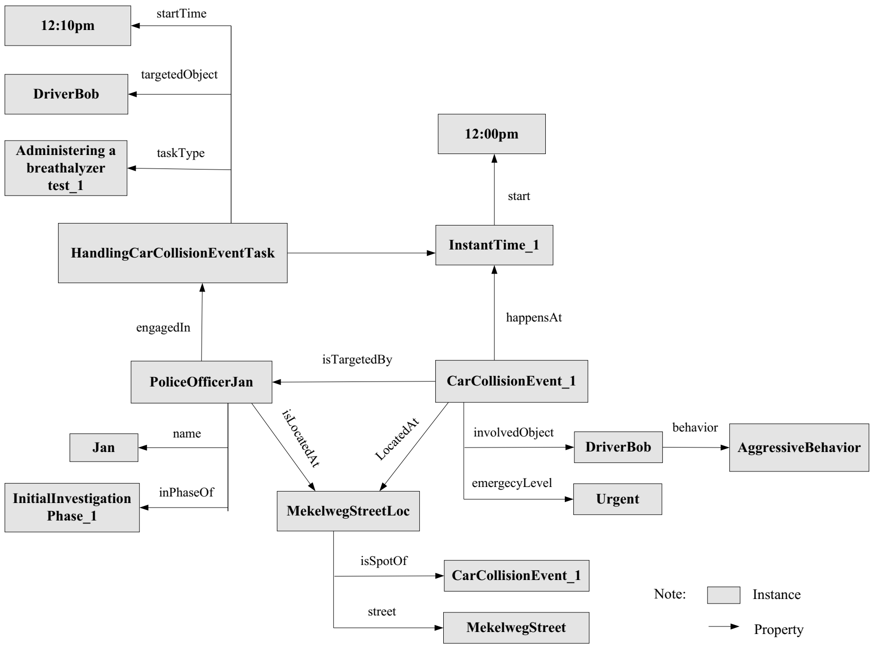

Figure 5.6: RDF Graph Notations for a Situation

- A police officer (*role*) "Jan" (*name*) is located at "Mekelweg", who is targeted at a car collision event. He is engaged in administering a breathalyzer test (*taskType*), and he is in the phase of initial investigation.

- The task of handling a car collision event is targeted at a driver "Bob" (*targetedObject*). This task starts at "12:10pm" (*startTime*).

- The urgent (*emergencyLevel*) event involves a driver "Bob" (*involvedObject*) who has aggressive behaviors (*behavior*). This event happens at "12:00pm" and locates at "Mekelweg". This event is targeted by police officer "Jan".

5.4 Conclusion

In this chapter we have discussed how information items from various data sources are modeled using RDF. We focused in particular on developing a context model which consists of a generic ontology and a domain-specific ontology. The generic ontology defines the high-level concepts of context which can be reused and extended in different domains; while the domain-specific ontology defines the details of general concepts and their properties specific for the domain of mobile police work. In the following chapters, we will focus on the formalism for expressing rules as well as the design of a corresponding rule engine for executing these rules in order to assess the relevance of information items in given contexts.

Part IV

Implementation

Chapter 6

Message Rating Rule Language

In Chapter 4 we presented our architecture, *CIDA*, which is designed to deliver relevant information contextualized to mobile users' current situations. CIDA consists of an information item repository, a situational data repository, a rule store and a relevance assessment rule engine. In Chapter 5 we described how the various sources of information are modelled using ontologies in order to formalize the information items and context information. In this chapter, we define the rule language MRRL (Message Rating Rule Language) to express declarative rules.

6.1 Introduction

The study presented in Chapter 3 has revealed the typical information needs of end-users for different categories of information in given phases they are involved in. In our scenarios, examples of consecutive phases are: (1) departure, (2) arrival, (3) initial investigation, and (4) further investigation. We derived the requirement that a successful system for contextualized delivery of relevant information should take into account not only the generic task but also the concrete phase end-users are in.

Moreover, we learned the conditions which can determine the relevance of information items. Most of the conditions refer to the contextual situation of police officers as described in the scenarios, including police officers' current *location*, *destination*, *task at hand*, *targeted event*, *nearby events*, *targeted objects*, and the specific *phase* they involved in. Other conditions are derived from the comparisons of spatio-temporal relations between objects. Examples of such relations that determine relevance are a temporal comparison between the start time of a user's task and the report time of a message or a spatial comparison between the location of a user and an event. Besides, it is also necessary to consider the *information category*. Accordingly, a system should be able to decide which information is relevant for a user in a given context by evaluating the above conditions.

To meet the requirements, we defined MRRL that is pronounced as "Merrill", building on an available standard rule language, i.e. SWRL[1] (Semantic Web Rule Language), and adapting it for the purpose of generating a cumulative rating for a given user/message pair.

[1]http://www.w3.org/Submission/SWRL/

Essentially, the conditions that need to be fulfilled are specified in the body of the rules and the head specifies the degree of relevance of a certain information item for a particular user given that these conditions are satisfied. MRRL is sufficiently expressive to deal with the scenarios we considered while containing no constraint that is only specific for our application domain. It is understandable for domain experts and allows them to easily engineer rules. More importantly, MRRL supports the reconfiguration of the behavior of a system without the need for reprogramming.

The chapter is organized as follows. In the next section we illustrate how rules were engineered to express the scenarios we presented earlier in the domain of police work. We present the syntax of MRRL in Section 6.3 and its semantics in Section 6.4. We finally conclude in Section 6.5.

6.2 Rule Engineering

Our information need study has revealed how the demands of end-users for given categories of information can change within the specific phase they are in (see Chapter 3). The observations from the study enabled us to define *high-level* rules which roughly express some basic information needs. Further, by the analysis of implicit attributes of a number of information items, such as spatio-temporal context, we refined those *high-level* rules and defined *intermediate* rules by taking into account the derived conditions that determine relevance. Finally, we engineered *formal* rules which were precisely formalized by the combination of a list of conditions and the specification of relevance ratings. In the following, we explain how the rules for navigation information and personal safety information were engineered through the three steps mentioned above, and thus elaborate how our rule language was designed.

Rules for Navigation Information. Let us consider the needs for navigation information which guides police officers to arrive at the incident spot in the fastest way. Such information could be the current traffic conditions from dynamic information sources with real-time information and also route instructions from sources with static geographic information. By the comparison of relevance of all information items as navigation information, the *high-level* rules (HLRul) for this type of information in given phases could be derived as:

- HLRul 1.1: When navigation information is related to the targeted event, it is *highly relevant* for police officers who are in the phase of departure (i.e. police officers are dispatched by the CCR and are about to quickly depart for the incident spot).
- HLRul 1.2: When navigation information is related to the targeted event, it is *irrelevant* for police officers who have already arrived at the scene of the incident.
- HLRul 1.3: When navigation information is related to nearby events, it is *highly relevant* for police officers who are in the phase of departure.
- HLRul 1.4: When navigation information is related to nearby events, it is *moderately relevant* for police officers who have arrived at the scene of the incident.
- HLRul 1.5: When navigation information is related to nearby events, it is *irrelevant* when police officers have started to investigate the incident.

Through the analysis of attributes of information items in this category, we found that the spatio-temporal attribute implicitly described in those items should be explicitly represented in order to compare it to the spatio-temporal context of users. For example, consider one message that reports a traffic jam; such a message is relevant on the condition that it should be reported in real-time and the reported event has happened nearby the destination of the police unit. In the following *intermediate* rules, we assume that messages should be reported no later than 30 minutes before the task has started, but this temporal condition can be modified according to specific requirements. Also, by taking into account the relationships between context dimensions that refer to the user's task, targeted event, and phase, we derived the conditions for determining relevance of navigation information. The *intermediate* rules (IMRul) listed as follows can be expressed in such a way: when a list of conditions are satisfied, the degree of relevance of a certain information item for a given user is determined.

- IMRul 1.1: **If** a message is of type navigation information, **and** this message describes an event which is targeted by a user, **and** the location described in this message is the user's destination, **and** the user is in the phase of departure, **and** the user is engaged in a task starting at a certain time, **and** the message is reported no later than 30 minutes before the task has started, **then** the message is *highly relevant* for the user.
- IMRul 1.2: **If** a message is of type navigation information, **and** this message describes an event which is targeted by a user, **and** the location described in this message is the user's destination, **and** the user is in the phase of arrival **or** initial investigation **or** further investigation, **then** the message is *irrelevant* for the user.
- IMRul 1.3: **If** a message is of type navigation information, **and** this message describes an event, **and** this event happens nearby the location of another event which is targeted by a user, **and** the user is in the phase of departure, **and** the user is engaged in a task starting at a certain time, **and** this message is reported no later than 30 minutes before the task has started, **then** the message is *highly relevant* for the user.
- IMRul 1.4: **If** a message is of type navigation information, **and** this message describes an event, **and** this event happens nearby the location of another event which is targeted by a user, **and** the user is in the phase of arrival, **and** the user is engaged in a task starting at a certain time, **and** this message is reported no later than 30 minutes before the task has started, **then** the message is *moderately relevant* for the user.
- IMRul 1.5: **If** a message is of type navigation information, **and** this message describes an event, **and** this event happens nearby the location of another event which is targeted by a user, **and** the user is in the phase of initial investigation **or** further investigation, **then** the message is *irrelevant* for the user.

Finally, the above *intermediate* rules were formalized in our rule language by these two steps: (1) the conditions specified by the **if** statement were expressed by triple patterns and combined by logical operators; and (2) the degree of relevance was mapped to a numerical rating level in line with users' judgements, i.e. *highly relevant* corresponds to a numerical rating level of $+5.0$, *moderately relevant* corresponds to $+2.0$ and *irrelevant* corresponds to -1.0. Taking into account the fact that the relevance of a certain information item for a given user could be specified by different rules, e.g. the conditions in IMRul 1.1 and IMRul 1.3 could be satisfied concurrently and thus these two rules interact together for a given message/user pair, we encoded the action of updating rating in order to specify how to update the relevance rating of given information items as the value indicated in the rule head. The *formal* rules (Rule) for navigation information are illustrated below:

- *Rule 1.1*: **infoType** ($?msg$, NaviInfo) & **describedEvent** ($?msg$, $?event$) & **isTargetedBy** ($?event$, $?user$) & **engagedIn** ($?user$, $?task$) & **describedLoc** ($?msg$, $?loc$) & **isDestinationOf** ($?loc$, $?user$) & **inPhaseOf** ($?user$, Departure) & **reportTime** ($?msg$, $?reportTime$) & **startTime** ($?task$, $?startTime$) & [$?reportTime \geq ?startTime$ - 30m]
  $\Longrightarrow$
  updateRating$(+5.0)$
- *Rule 1.2*: **infoType** ($?msg$, NaviInfo) & **describedEvent** ($?msg$, $?event$) & **isTargetedBy** ($?event$, $?user$) & **describedLoc** ($?msg$, $?loc$) & **isDestinationOf** ($?loc$, $?user$) & (**inPhaseOf** ($?user$, Arrivial) | **inPhaseOf** ($?user$, InitialInvestigation) | **inPhaseOf** ($?user$, FurtherInvestigation))
  $\Longrightarrow$
  updateRating(-1.0)
- *Rule 1.3*: **infoType** ($?msg$, NaviInfo) & **describedEvent** ($?msg$, $?event$) & **locatedAt** ($?event$, $?eveLoc$) & **nearby** ($?eveLoc$, $?tarloc$) & **isSpotOf** ($?tarloc$, $?tarEve$) & **isTargetedBy** ($?tarEve$, $?user$) & **inPhaseOf** ($?user$, Departure) & **engagedIn** ($?user$, $?task$) & **startTime** ($?task$, $?startTime$) & **reportTime** ($?msg$, $?reportTime$) & [$?reportTime \geq ?startTime$ - 30m]
  $\Longrightarrow$
  updateRating$(+5.0)$
- *Rule 1.4*: **infoType** ($?msg$, NaviInfo) & **describedEvent** ($?msg$, $?event$) & **locatedAt** ($?event$, $?eveLoc$) & **nearby** ($?eveLoc$, $?tarloc$) & **isSpotOf** ($?tarloc$, $?tarEve$) & **isTargetedBy** ($?tarEve$, $?user$) & **inPhaseOf** ($?user$, Arrival) & **engagedIn** ($?user$, $?task$) & **startTime** ($?task$, $?startTime$) & **reportTime** ($?msg$, $?reportTime$) & [$?reportTime \geq ?startTime$ - 30m]
  $\Longrightarrow$
  updateRating$(+2.0)$
- *Rule 1.5*: **infoType** ($?msg$, NaviInfo) & **describedEvent** ($?msg$, $?event$) & **locatedAt** ($?event$, $?eveLoc$) & **nearby** ($?eveLoc$, $?tarloc$) & **isSpotOf** ($?tarloc$, $?tarEve$) & **isTargetedBy** ($?tarEve$, $?user$) & ((**inPhaseOf** ($?user$, InitialInvestigation) | **inPhaseOf** ($?user$, FurtherInvestigation))
  $\Longrightarrow$
  updateRating(-1.0)

As our rule language defines, two special variables are appointed in the rule body: $?msg$ and $?user$. When all conditions specified in the rule body are fulfilled, the relevance rating of given information items ($?msg$) for given users ($?user$) is incremented with the value indicated in the rule head. The conditions specified in the rule body could become quite complex by combining them with logical operators: the logical conjunction “&” represents that all the conditions need to be satisfied, and the disjunction “|” represents that at least one condition should be met. In addition, the time constraint is expressed with arithmetic or comparison operators in brackets.

Rules for Personal Safety Information. In order to further explain how our language is defined by investigating the critical conditions for the relevance assessment. Let us consider the information needs for personal safety information. The personal safety information, such as violence or aggressive behaviors of a suspect, is crucial for police officers to guarantee the safety for themselves as well as for others. We defined *high-level* rules (HLRul) for such information according to the observations from the study.

- HLRul 2.1: In general, personal safety information is *relevant* for police officers in all phases of handling an event.
- HLRul 2.2: Its relevance in the phase of further investigation is *relatively lower* compared to the other three phases.

By comparing the relevance of all information items in this category, we found that when personal safety information is reported in real-time, such as a real-time report concerning the aggressive behavior of a driver involved in a car collision incident, its relevance is higher than when it concerns personal background information, e.g. a suspect possesses an aggressive dog. In addition to the conditions considered to assess the relevance of navigation information, consisting of time, targeted event, task and phase, two other important conditions should be taken into account: (1) whether the objects described in the information items are involved in an event? (2) Whether this event is targeted by the police officers? The *intermediate* (IMRul) rules for personal safety information were defined as:

- IMRul 2.1: **If** a message is of type personal safety information, **and** the object described in this message is a person who is involved in an event, **and** the event is targeted by a user, **and** the user is engaged in the phase of departure **or** arrival **or** initial investigation, **then** this message is *highly relevant*.
- IMRul 2.2: **If** a message is of type personal safety information, **and** the object described in this message is a person who is involved in an event, **and** the event is targeted by a user, **and** the user is engaged in the phase of further investigation, **then** this message is *moderately relevant*.
- IMRul 2.3: **If** a message is of type personal safety information, **and** the object described in this message is a person who is involved in an event, **and** the event is targeted by a user, **and** the message is reported after the event has happened, then the message is *moderately relevant*.

In the same manner, we defined *formal* rules specifying the relevance of personal safety information in a given context in our rule language as:

- *Rule 2.1*: **infoType** ($?msg$, PersonalSafety) & **describedObject** ($?msg$, $?person$) & **isInvolvedIn** ($?person$, $?event$) & **isTargetedBy** ($?event$, $?user$) & (**inPhaseOf** ($?user$, Departure) | **inPhaseOf** ($?user$, Arrival) | **inPhaseOf** ($?user$, InitialInvestigation))
  $\Longrightarrow$
  updateRating $(+5.0)$

- *Rule 2.2*: **infoType** ($?msg$, PersonalSafety) & **describedObject** ($?msg$, $?person$) & **isInvolvedIn** ($?person$, $?event$) & **isTargetedBy** ($?event$, $?user$) & **inPhaseOf** ($?user$, FurtherInvestigation)
  $\Longrightarrow$
  updateRating $(+2.0)$

- *Rule 2.3*: **infoType** ($?msg$, PersonalSafety) & **describedObject** ($?msg$, $?person$) & **isInvolvedIn** ($?person$, $?event$) & **isTargetedBy** ($?event$, $?user$) & **happensAt** ($?event$, $?eventTime$) & **reportTime** ($?msg$, $?reportTime$) & [$?reportTime \geq ?eventTime$]
  $\Longrightarrow$
  updateRating $(+2.0)$

Derived Conditions. We have shown formal rules defined for navigation and personal safety information. In order to establish in general the conditions which determine the relevance of typical categories of information police officers often deal with, we also derived the requirements from the study for information concerning:

1. Criminal records.
2. Social relations.
3. Attributes of nearby incidents.
4. Medical history.
5. Priority activities of colleagues.
6. Incidence evidence.

In addition to the two conditions concerning the user's phase and information category observed from the study, we can derive the main required types of conditions for assessing the relevance of information items as follows:

1. A spatial relation between an event and a user.
2. A spatial relation between different events, such as a targeted event and other events.
3. A temporal relation between report time of an information item and start time of a user's task.
4. A temporal relation between report time of an information item and start time of an event.

5. A relation between a user and an event, e.g. whether a user is targeted at an event.

6. A relation between the described objects and an event, e.g. whether the objects described in information items are involved in an event.

6.3 MRRL Syntax

MRRL is defined here for expressing formal rules, such as illustrated in Section 6.2. The MRRL grammar is an LL(1) grammar (Griffiths, 1974). A context free grammar is an LL(1) grammar if and only if any two productions with the same left-hand sides have different select sets[2].

MRRL Grammar. We present the MRRL Grammar represented by the 41 corresponding rules in the following. Specifically, the main syntax is represented by the 14 rules (from rule 6.1 to 6.14), and the syntax of the *time filter* expression is represented by the 27 rules (from rule 6.15 to 6.41).

The MRRL grammar is specified by terminal and non-terminal symbols, which are two disjoint sets defined as:

- Terminal symbols. Terminal symbols are regular token objects expressed by the regular expressions, which are the elementary symbols of MRRL that cannot be replaceable. For example, literal strings (e.g. "updating"), numbers (e.g. $+5.0$), mathematic operators (e.g. +, $\geq$), special characters (e.g. \$, ?), and also logical operators (i.e. & and $|$).

- Non-terminal symbols. Non-terminal symbols are a specific set of symbols introduced to help describe the structure of the MRRL grammar. Non-terminal symbols can be replaced by terminal symbols; thus they are composed of some combination of terminal and non-terminal symbols. For instance, the starting non-terminal "Rule" (6.1) consists of two non-terminals: "Body" (6.2) and "Head" (6.3); the non-terminal *Triple* (6.8) consists of three non-terminal symbols, i.e. *Predicate* (6.9), *Subject* (6.10) and *Object* (6.11), and also three terminal symbols, i.e. "(", ")", and ",".

[2] http://www.cs.uky.edu/~lewis/essays/compilers/ll-lang.html

$$<Rule> \quad := \quad <Body> \text{“} \implies \text{”} <Head> \tag{6.1}$$

$$<Body> \quad := \quad <RuleExp> \mid \text{“(”} <RuleExp> \text{“)”} \tag{6.2}$$

$$<Head> \quad := \quad \text{“}updateRating\text{”“(”} <Decimal> \text{“)”} \tag{6.3}$$

$$<RuleExp> \quad := \quad <OrExp> \tag{6.4}$$

$$<OrExp> \quad := \quad <AndExp> \ (\text{“} \mid \text{”} <AndExp>)* \tag{6.5}$$

$$<AndExp> \quad := \quad <TriExp> \ (\text{“\&”} <TriExp>)* \tag{6.6}$$

$$<TriExp> \quad := \quad <Triple> \mid \text{“(”} <OrExp> \text{“)”} \mid <TimeFilterExp> \tag{6.7}$$

$$<Triple> \quad := \quad <Predicate> \text{“(”} <Subject> \text{“,”} <Object> \text{“)”} \tag{6.8}$$

$$<Predicate> \quad := \quad <String> \tag{6.9}$$

$$<Subject> \quad := \quad <ComVar> \mid <String> \tag{6.10}$$

$$<Object> \quad := \quad <ComVar> \mid <String> \tag{6.11}$$

$$<ComVar> \quad := \quad \text{“?”} <String> \tag{6.12}$$

$$<String> \quad := \quad ([\text{”A”} - \text{”Z”}, \text{”a”} - \text{”z”}]) + ([\text{”0”} - \text{”9”}])* \tag{6.13}$$

$$<Decimal> \quad := \quad ([\text{”+”}, \text{”}-\text{”}][\text{”0”} - \text{”9”}]) + \text{”.”}([\text{”0”} - \text{”9”}])* \tag{6.14}$$

$$<TimeFilterExp> \quad := \quad \text{“[”} <TimeFilterOrExp> \text{“]”} \tag{6.15}$$

$$<TimeFilterOrExp> \quad := \quad <TimeFilterAndExp> (\text{“} \mid \text{”} <TimeFilterAndExp>)* \tag{6.16}$$

$$<TimeFilterAndExp> \quad := \quad <TimeComparisonExp> (\text{“\&”} <TimeComparisonExp>)* \tag{6.17}$$

$$<TimeComparisonExp> \quad := \quad <MomentCal> \ (<GreatThanExp> \mid <NotGreatThanExp> \mid <LessThanExp> \mid <NotLessThanExp> \mid <EqualExp>)? \tag{6.18}$$

$$<GreaterThanExp> \quad := \quad \text{“>”} <MomentCal> \tag{6.19}$$

$$<NotGreaterThanExp> \quad := \quad \text{“} \leq \text{”} <MomentCal> \tag{6.20}$$

$$<LessThanExp> \quad := \quad \text{“<”} <MomentCal> \tag{6.21}$$

$$<NotLessThanExp> \quad := \quad \text{“} \geq \text{”} <MomentCal> \tag{6.22}$$

$$<EqualExp> \quad := \quad \text{“} = \text{”} <MomentCal> \tag{6.23}$$

$$<MomentCal> \quad := \quad <MomentExp> (<AddTimeCal> \mid <MinusTimeCal>)* \tag{6.24}$$

$$<MomentExp> \quad := \quad <ComVar> \mid <CurrentTimeVar> \mid <DateTime> \tag{6.25}$$

$$<AddTimeCal> \quad := \quad \text{“} + \text{”} <DurationExp> \tag{6.26}$$

$$<MinusTimeCal> \quad := \quad \text{“} - \text{”} <DurationExp> \tag{6.27}$$

$$<DurationExp> \quad := \quad <SecondExp> \mid <MinuteExp> \mid <HourExp> \mid <DayExp> \mid <MonthExp> \mid <YearExp> \mid <DurationCal> \tag{6.28}$$

$$<DurationCal> \quad := \quad <ComVar> \text{“} - \text{”} <ComVar> \mid <DateTime> \text{“} - \text{”} <DateTime> \tag{6.29}$$

$$<DateTime> \quad := \quad <Date><Time> \tag{6.30}$$

$$<Date> \quad := \quad <Year> \text{“/”} <TwoDigit> \text{“/”} <TwoDigit> \tag{6.31}$$

$$<YearExp> \quad := \quad (<Integer> \mid <TwoDigit>) \text{“Y”} \tag{6.32}$$

$$<MonthExp> \quad := \quad (<Integer> \mid <TwoDigit>) \text{“M”} \tag{6.33}$$

$$<DayExp> \quad := \quad (<Integer> \mid <TwoDigit>) \text{“D”} \tag{6.34}$$

$$<HourExp> \quad := \quad (<Integer> \mid <TwoDigit>) \text{“h”} \tag{6.35}$$

$$<MinuteExp> \quad := \quad (<Integer> \mid <TwoDigit>) \text{“m”} \tag{6.36}$$

$$<SecondExp> \quad := \quad (<Integer> \mid <TwoDigit>) \text{“s”} \tag{6.37}$$

$$<Time> \quad := \quad <TwoDigit> \text{“ : ”} <TwoDigit> \text{“ : ”} <TwoDigit> \tag{6.38}$$

$$<Year> \quad := \quad [\text{”0”} - \text{”9”}][\text{”0”} - \text{”9”}][\text{”0”} - \text{”9”}][\text{”0”} - \text{”9”}] \tag{6.39}$$

$$<TwoDigit> \quad := \quad [\text{”0”} - \text{”9”}][\text{”0”} - \text{”9”}] \tag{6.40}$$

$$<CurTimeVar> \quad := \quad \text{“\$”} <String> \tag{6.41}$$

MRRL Syntax Specification. A rule consists of a rule body and a rule head. The rule body contains a list of conditions that are combined together with the intersection operator (logical conjunction) "&", the union operator (logical disjunction) "|", as well as arithmetic and comparison operators for temporal expressions. The rule head (6.3) consists of a literal string "updateRating" and a decimal number with brackets.

The basic term of conditions is either a triple (6.8) or a time filter expression (6.15). Each triple is represented in the form of $predicate(subject, object)$. The *predicate* represented by a string is predefined as a property of a subject; both of the *subject* and the *object* could be a class or a variable. For example, **infoType**($?msg$, PersonalSafety) represents a condition that a message ($?msg$) should be an instance in the class of personal safety information.

A time filter expression is represented in brackets. It supports comparison operators (6.18), including the operations of greater than (6.19), not greater than (6.20), less than (6.21), not less than (6.22), and equal (6.23). Also, it supports arithmetic operators, including plus and minus a period of time (6.26 and 6.27), e.g. $+5Y$ means plus 5 years, and $-20s$ means minus 20 seconds.

MRRL supports three types of temporal expressions:

1. Basic time comparison, such as "[?reportTime = 2010/01/31 23:59:59 - 20s]"; and also "[?reportTime $\leq$ \$now - 20m]", which indicates the condition that the reporting time should earlier than 20 minutes ago.

2. Multiple time comparisons. For example, "[?happenTime $\leq$?reportTime $\leq$?startTime + 30m]", it defines that the message is reported after the event has happened but no later than 30 minutes after the task has started.

3. Composed expressions combined with the logical operators. For instance, "[?reportTime $>$ 2010/01/31 23:59:59 | ?happenTime $\leq$?reportTime $\leq$?startTime + 30m]"; and also "[?reportTime $>$ 2010/01/31 23:59:59 & ?reportTime $\leq$ \$now - 20m]".

By parsing a rule expression, an abstract syntax tree (AST) can be generated according to the MRRL grammar. When parsing an expression, the corresponding parser scans from left-to-right and parses by constructing a leftmost derivation, which means the left-most non-terminal is always replaced the first and the longest rule is chosen by a parser to match (Aho and Ullman, 1972). Take the Rule 2.1 for example, the syntax of this rule can be represented by an AST as Figure 6.1 shows. Terminal symbols are leaves of the syntax tree, non-terminal symbols are nodes of the tree and each node expands by the production into the next level of the tree.

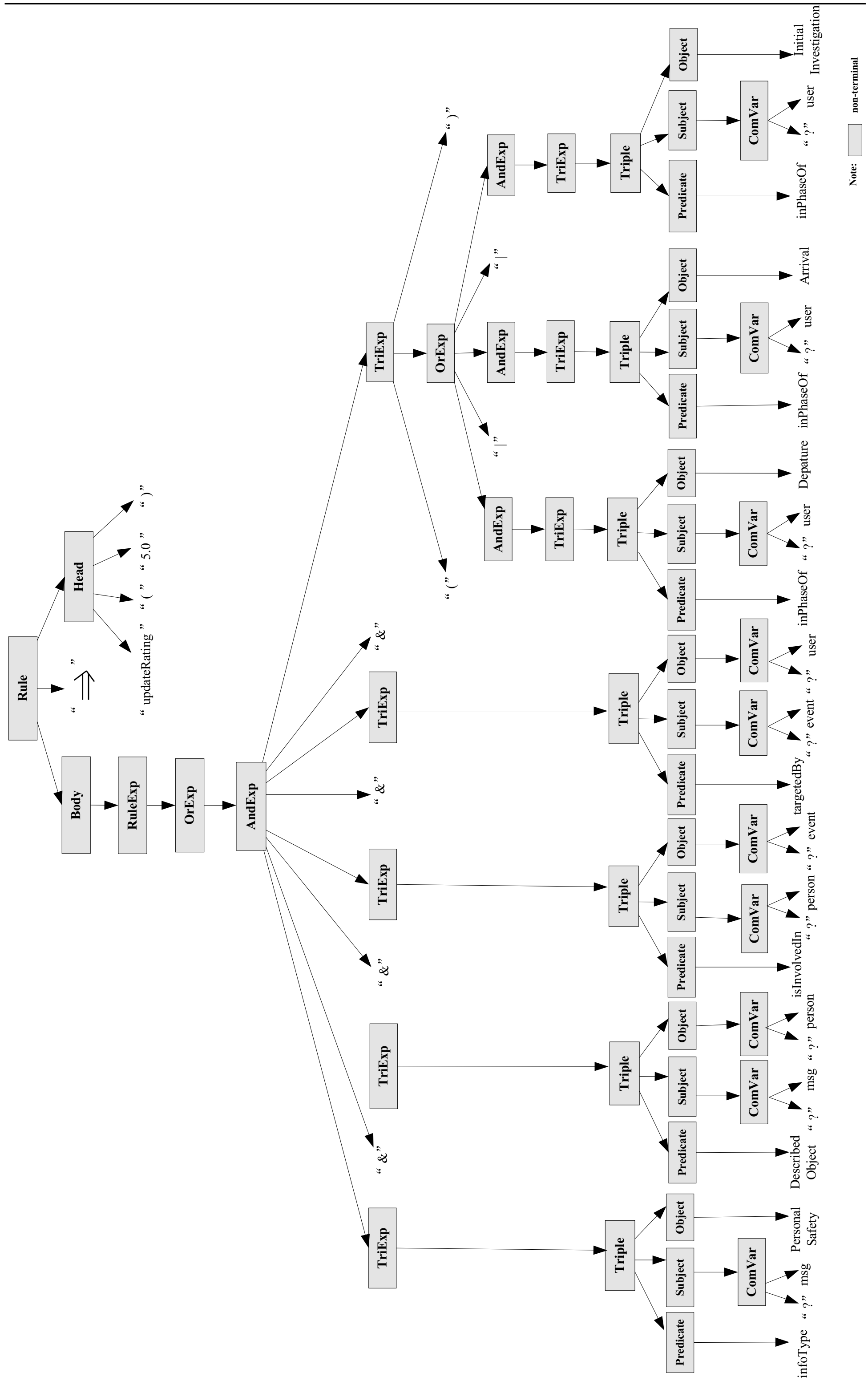

Figure 6.1: The Abstract Syntax Tree For Rul 2.1

6.4 MRRL Semantics

Rule Body. The rule body specifies conditions that need to be fulfilled in a certain context. As explained in Section 6.2, two special variables are appointed in the rule body: $?msg$ and $?user$. When all conditions in the rule body are satisfied, the relevance rating for the combinations of given information items ($?msg$) for given users ($?user$) is incremented with the value indicated in the rule head.

Rule Head. The rule head determines how relevance ratings are updated in case all conditions in the rule body are satisfied.

Rule Interaction. The original relevance rating for each msg/user pair starts with zero. All the rules in a rule store interact with each other to determine the final rating for the relevance of a given msg/user pair.

It is important to note that the relevance of a given information item for a specified user can be modified by different rules concurrently according to different assessment criteria. One reason is that a certain information item could be categorized into more than one information categories. For instance, one message stating that a subject is potentially in possession of illegal weapons is not only of type *personal safety* information, but also of type *criminal record*. Also, the relevance of an information item of a certain category could be determined by different rules. For example, one rule could specify that the relevance of a message reporting aggressive actions by a driver should be increased by $+5.0$ for officer "Kees" who is investigating this driver. Another rule could specify that the relevance of the same message should be increased by $+2.0$ for officer "Kees", since the message has just been received 10 minutes ago and it is related to the event targeted by "Kees". In case this message meets the conditions defined in the head of both rules, the cumulative final rating of this message for officer "Kees" would be $+7.0$.

6.5 Conclusion

In this chapter, we have presented the formalism for expressing rules which determine the relevance of information items by taking into account the situation-specific information needs of end-users. We illustrated how rules were engineered by three steps. First, on the basis of the observations from the study, we identified the requirements for different categories of information in particular phases and thus defined *high-level* rules. Then, we refined these *high-level* rules by taking into account the derived conditions for determining the relevance and thus built *intermediate* rules. Finally, the *formal* rules were formalized in MRRL. We presented the MRRL grammar and showed its expressivity. Also, we explained the semantics of MRRL.

In the next chapter, we will present how we design and implement a rule engine to execute MRRL rules.

Chapter 7

Relevance Assessment Rule Engine

We have presented our rule language (MRRL) in Chapter 6. In this chapter we elaborate the implementation of the Relevance Assessment Rule Engine (RARE). RARE is able to execute a set of MRRL rules by evaluating the conditions specified in the rule body. Given that the conditions in the body are met, RARE updates the relevance rating of certain information items for specific users as specified in the rule head. We provide the design of the main components of RARE and the implementation of algorithms.

7.1 Introduction

With the goal of demonstrating the feasibility of our rule-based architecture (CIDA), we developed the Contextualized Relevance Assessment System (CRAS), which can assess the relevance of information items according to the contextual situation of end-users. CRAS consists of a rule engine (RARE) and an ontology-based context model as well as an information item model (see Chapter 5).

RARE is a crucial component which supporting the reconfiguration of the behavior of CRAS by the specification of different sets of MRRL rules. Through taking into account the context information in the *situational data repository*, RARE realizes the core functionality of assessing the relevance of information items by executing the rules. As explained in Chapter 4 and 5, all information consists of context information and information items is expressed and available in RDF. Given that MRRL was inspired by the SWRL[1], RARE was designed to translate the rule body into a SPARQL[2] query which can be evaluated by standard Semantic Web query engines. Moreover, RARE computes the relevance ratings specified in the rule head. In this way, the translated rules interact together to increase or decrease the relevance of information in the *information item repository*, adding up the effect to produce a final ranking at different time points. The ranking can be used by the

[1] http://www.w3.org/Submission/SWRL/
[2] http://www.w3.org/TR/rdf-sparql-query/

message presentation component to choose the appropriate amount of relevant information items (messages) for end-users.

The chapter is organized as follows. Section 7.2 presents the conceptual description of the relevance assessment process. Section 7.3 provides the design and the implementation of RARE. Finally, Section 7.4 arrives at the conclusion.

7.2 Conceptual Description of the Relevance Assessment Process

The process for the relevance assessment is shown in Figure 7.1. In principle, RARE is triggered to execute rules once context is updated or a new information item is received. A much more efficient triggering mechanism could be defined to invoke rules, but it is not our focus. For each rule in a rule set, RARE evaluates all conditions in the rule body. If all conditions are fulfilled, the relevance of a certain information item is computed as indicated in the rule head. After all rules are executed, the cumulative ratings for given user/message pairs are collected and updated accordingly. A ranking is then generated which is used to select an appropriate number of information items to deliver. When RARE is triggered again, all ratings start from zero and information items are re-ranked for specific users.

7.3 Main Components

The rule engine consists of three main components: (1) the rule parser, (2) the query generator, and (3) the query evaluator. Each component is implemented as a Java package and the dependence relations between the packages are shown in Figure 7.2. The rule parser, which relies on JavaCC[3] to generate the parser of the rules, provides an abstract syntax tree (AST) to the query generator component. The query generator transforms these ASTs into SPARQL queries and passes them along to the query evaluator which evaluates the queries using the Sesame query engine[4]. The main functions of each component are elaborated in this section.

7.3.1 Rule Parser

The rule parser parses a given set of rules and builds the AST according to the rule syntax. A set of rules is parsed and returned as concatenated strings which will be used in the next step of query generation. Through compiling a ruleAST.jjt file which defines the rule grammar, Java CC generates a list of Java class files. The class files interact with the query generator component consisting of the class “SimpleNode.java” which has methods for the tree traverse and dump, and the class “ruleASTTreeConstants.java” which tags each tree node with an integer.

[3] https://javacc.dev.java.net/
[4] http://www.openrdf.org/

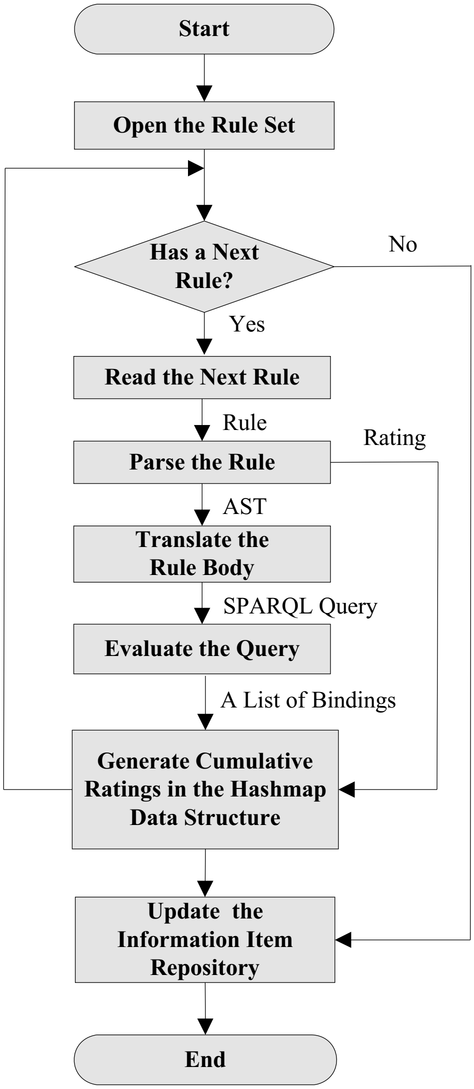

Figure 7.1: The Relevance Assessment Process

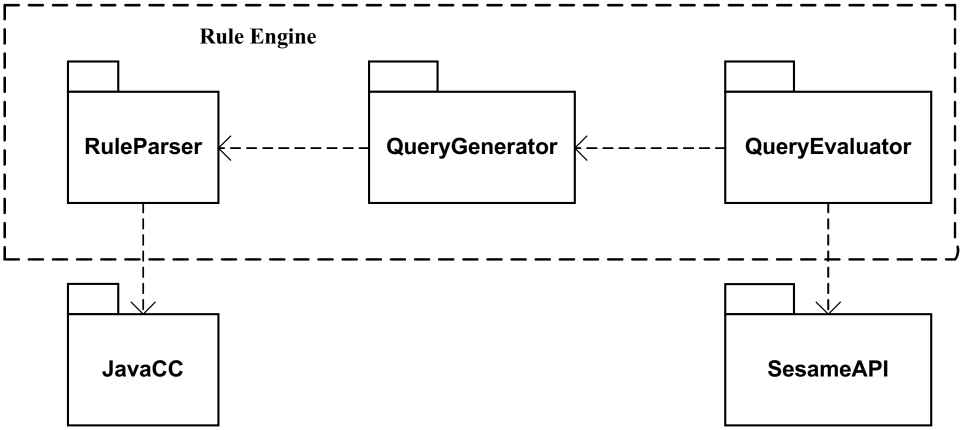

Figure 7.2: Java Packages and their relationships

7.3.2 SPARQL Query Generator

The SPARQL query generator recursively traverses the AST nodes in depth-first order and converts the whole tree to a query. The main function of this component is to translate the rule body into a SPARQL query.

Query Examples. To show how rules are translated into SPARQL queries, let us consider two rules shown in Chapter 6:

- *Rule 1.1*: **infoType** ($?msg$, NaviInfo) & **describedEvent** ($?msg$, $?event$) &
  isTargetedBy ($?event$, $?user$) & **engagedIn** ($?user$, $?task$) &
  describedLoc ($?msg$, $?loc$) & **isDestinationOf** ($?loc$, $?user$) &
  inPhaseOf ($?user$, Departure) & **reportTime** ($?msg$, $?reportTime$) &
  startTime ($?task$, $?startTime$) & [$?reportTime \geq ?startTime$ - 30m]
  $\Longrightarrow$
  updateRating$(+5.0)$

- *Rule 2.1*: **infoType** ($?msg$, PersonalSafety) & **describedObject** ($?msg$, $?person$) &
  isInvolvedIn ($?person$, $?event$) & **isTargetedBy** ($?event$, $?user$) &
  (**inPhaseOf** ($?user$, Departure) | **inPhaseOf** ($?user$, Arrival) |
  inPhaseOf ($?user$, InitialInvestigation))
  $\Longrightarrow$
  updateRating $(+5.0)$

The above rules are translated to a SPARQL query as Figure 7.3 and 7.4 show. When evaluated, each query returns message/user pairs, i.e. ($?msg$/$?user$) bindings. The set of triple patterns in the WHERE clause represents the conditions that need to be fulfilled as specified in the body of the corresponding rule.

A query consists of three parts: the PREFIX declarations, the SELECT clause and the WHERE clause.

1. The PREFIX declarations specify prefixes for short name usages (for example, here cd is declared as short name for $<$ http://ruleEngine.org/contextData/$>$).

2. The SELECT clause identifies the ($?msg$/$?user$) bindings to appear in the query results. Since $?msg$ and $?user$ are two special variables specified in the rule body, each query returns message/user pairs.

3. The WHERE clause provides the basic graph pattern to match against the data graph. The basic graph pattern in the query example shown in Figure 7.3 consists of several triple patterns. Each triple pattern, such as "$?user$ cd: engagedIn $?task$", is translated from each condition defined in the rule body.

```
PREFIX   rdf: <http:// www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX   cd:  <http://ruleEngine.org/ contextData />

SELECT  ?msg  ?user
WHERE
{ ?msg    rdf: type     cd: NaviInfo .
  ?msg    cd: describedEvent   ?event .
  ?event  cd: isTargetedBy      ?user .
  ?user   cd: engagedIn         ?task .
  ?msg    cd: describedLoc      ?loc .
  ?loc    cd: isDestinationOf   ?user .
  ?user   cd: inPhaseOf         cd: Depature .
  ?msg    cd: reportTime        ?reportTime .
  ?task   cd: startTime          ?startTime .
   FILTER ( ?reportTime >= ?startTime - "1800000" ^^xsd:long )
}
```

Figure 7.3: A Query Translated from Rule 1.1

```
PREFIX   rdf: <http:// www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX   cd:  <http://ruleEngine.org/ contextData />

SELECT  ?msg  ?user
WHERE
{ ?msg    rdf: type     cd: PersonalSafety .
  ?msg    cd: describedObject    ?person .
  ?person   cd: isInvolvedIn      ?event .
  ?event  cd: isTargetedBy        ?user .
  { ?user  cd: inPhaseOf  cd: Departure } UNION
  { ?user  cd: inPhaseOf  cd: Arrival}       UNION
  { ?user  cd: inPhaseOf  cd: InitialInvestigation} .
}
```

Figure 7.4: A Query Translated from Rule 2.1

As shown in the above queries, the process of rule body translation is summarized as:

- Intersection expressions, i.e. triples combined by the conjunction operator "&", are translated into basic graph patterns. Each triple expression, such as *isTargetedBy (?event, ?user)* (see Rule 1.1) is converted to a single graph pattern like *?event, cd:isTargetedBy ?user* (see Figure 7.3).

- Alternation expressions, i.e. triples connected by the disjunction operator "|", are translated into UNION patterns (see Figure 7.4).

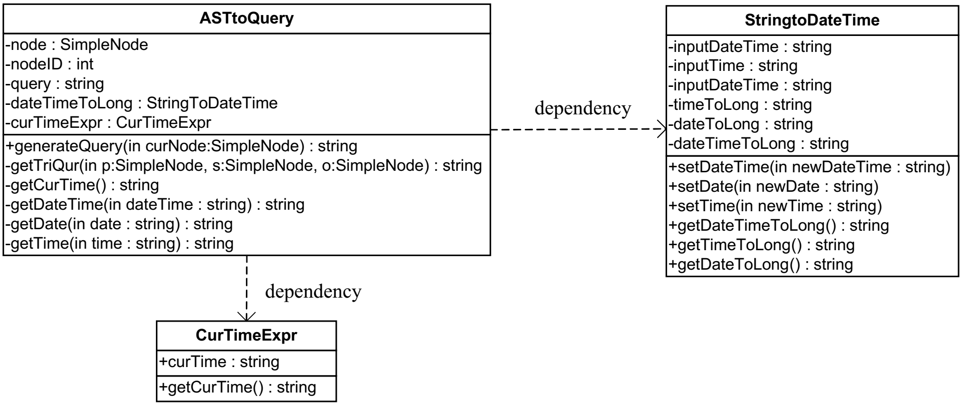

Figure 7.5: Classes and Their Relationships in the Query Generator

- Time constraint expressions, i.e. temporal operations represented in brackets, are mapped to FILTER expressions (see Figure 7.3).

Methods. The function of query generation is mainly implemented by the method “generateQuery()”. In particular, the method “getTriQur()” is specialized on translating the TRIPLE Node into a triple pattern. For time filter expressions, the class “StringToDateTime” translates the input string into an appropriate format of Date, Time or dateTime, and further convert it to milliseconds; the class “CurTimeExp” recognizes the special variable “$now” and gets the current time. Figure 7.5 shows the relationships of classes in the query generator component.

SPARQL Query Translating Algorithm. The SPARQL query translating algorithm recursively traverses the AST tree and translates the AST nodes to the specified query expressions by invoking the corresponding methods. It returns a query string combined with operators. This algorithm is shown in Algorithm 1.

The types of generated AST nodes from the rule parser are annotated by identifers. By matching the identifier of the current node, it can determine which method is invoked to translate the corresponding node. For example, when a Triple node is reached, the method “getTriQur()” is invoked to construct its three children of *predicate* and *subject* and also *object* to a triple pattern. When an OR expression node is reached, its first child with the corresponding branches is recursively traversed. The translation results are concatenated with the next translated expressions from other children by “UNION” symbols. After all children nodes are walked through, it will return to the root node where tree traversal was started, and thus generate a SPARQL query.

7.3.3 Query Evaluator

The query evaluator evaluates the translated queries and updates the relevance rating in the *information item* repository. The function of this component is fulfilled by two steps: (1) rat-

Algorithm 1: SPARQL Query Mapping
Input: AST Node
Output: A Query String

```
GENERATE_QUERY (curNode)
switch curNode.type
  case TripleNode :
      for three children, P,S,O do
          qr ← getTriQur(P,S,O) od
  case AndExpNode :
      qr ← GENERATE_QUERY(curNode.child(0))
      for (i = 1; i < curNode.getNumChildren( ); ++i ) do
              qr ← qr + "\n" + GENERATE_QUERY(curNode.child(i)) od
  case OrExpNode :
      qr ← "{" + GENERATE_QUERY(curNode.child(0)) + "}"
      for (i = 1; i < curNode.getNumChildren( ); ++i ) do
              qr ← qr + "UNION { " + GENERATE_QUERY(curNode.child(i) + "}" od
  case TimeFilterExpNode :
      for (i = 0; i < curNode.getNumChildren( ); ++i ) do
          FilterExp ← FILTERMAPPING(curNode.child(i)) od
      qr ← qr + "FILTER ( "+ FilterExp + ") ."
  case default :
      for each curNode.child(n) do
          qr ← qr + GENERATE_QUERY(curNode.child(n)) od
return qr
end
```

ing aggregation and (2) rating updating. Figure 7.6 shows the classes and their relationships in the query evaluator component.

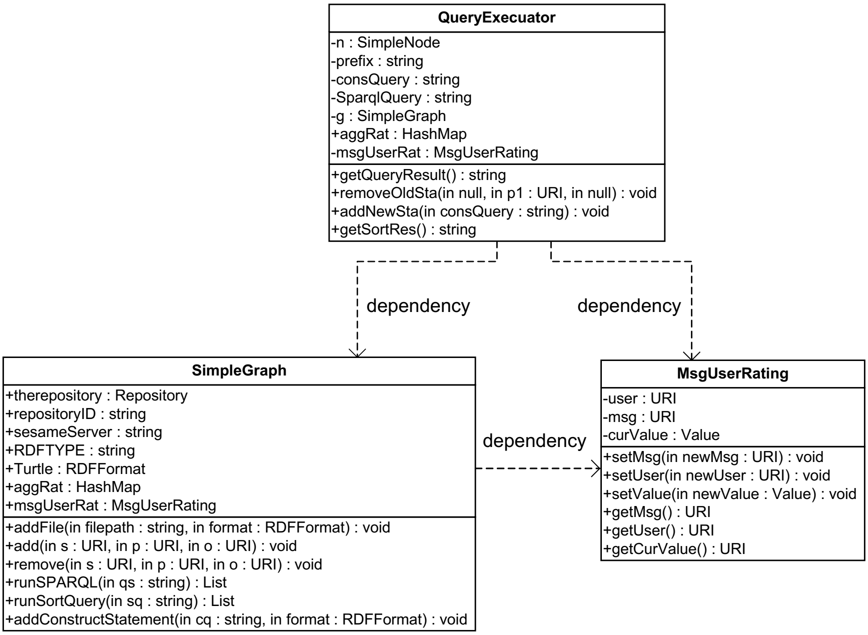

Figure 7.6: Classes and Their Relationships in the Query Evaluator

- **Rating aggregation**. The query evaluator connects with the *situational data* repository and evaluates all the translated SPARQL queries using the Sesame API. Then, it collects all the ratings for a message/user pair and accumulates them appropriately to yield a new rating value. The final cumulated ratings are recorded in a hashmap named "*aggRat*". The relation for each message/user pair is represented in a key, and the cumulated rating is recorded by a corresponding value.
- **Rating updating**. Firstly, the query evaluator deletes the previous ratings. Then, it constructs triples specifying new ratings for given message/user pairs according to the records in the Hashmap. Lastly, the query evaluator updates the *information item* repository with these new ratings.

Relevance Rating Aggregation Algorithm. The relevance rating aggregation algorithm is applied to accumulate the relevance ratings for given message/user pairs as shown in Algorithm 2.

Algorithm 2: Relevance Rating Aggregation
Input: binding, ratingValue.
Global Variable: HashMap aggRat(key, value).

```
AGGREGATE_RATING(binding, ratingValue)
begin
  for each binding(URI msg, URI user)  do
      key  = msg + "relevantTo" + user
      if  aggRat(key) == NULL  then
            aggRat.put(key, ratingValue)
         else
            aggRat.set(key, ratingValue + aggRat.getValue(key))
     end if
   end for
end
```

First of all, a HashMap "*aggRat(key, value)*" is initialized for storing the ($?msg$/$?user$) bindings returned by each query as the *key* and the corresponding ratings as the *value*. For each binding with a new rating, if its value already was stored in the Hashmap, then the previous value is incremented with the new value; if there is no key representing this binding, then a new key with its current value is recorded. After all bindings from query results have been enumerated, the final accumulated ratings are computed.

Relevance Rating Updating Algorithm The relevance rating updating algorithm is responsible for the updating the relevance ratings in the *information item* repository as illustrated in Algorithm 3.

For the purpose of updating the relevance rating in the *information item* repository, all the triples of type *?rating cd:value ?value* are first removed. In the next step, the Hashmap "*aggRat(key, value)*" recording the all message/user pairs with final aggregate ratings is enumerated, in order to get the URI of the object message ($?msg$) and the URI of the object user ($?user$) and also the value of the rating ($newValue$). For each entry, a triple is constructed by executing the query "conQue". Finally, all constructed triple patterns such as: "*cd:newRating cd:hasValue newValue ^^xsd:decimal*" are added into the *information item* repository and thus the relevance ratings are updated.

Algorithm 3: Relevance Rating Updating
Global Variable: HashMap aggRat(key, value);
Information Item Repository (IIR) .

```
UPDATE_RATING()
begin
    do remove all the triples in IIR of the form '(?rating  cd :hasValue  ?value)'  od
    for each entry in aggRat(key, value) do
          msgUser = entry.get(key)
          /* get the URI of the object message (?msg)*/
            msg = msgUser.getMsg()
         /* get the URI of the object user (?user) */
           user = msgUser.getUser()
         /* get the value of the rating */
           newValue = msgUser.getCurValue()
            String conQue = "CONSTRUCT { ?newRating   cd :hasValue newValue^^xsd:decimal }
                          WHERE { cd :msg     cd :hasRating      ?newRating .
                                      ?newRating   cd :isForUser    cd :user .}"
                 execute the query conQue and get the result R
                 add the result R to IIR od
    end for
end
```

7.4 Conclusion

In the context of CIDA, we developed CRAS for contextualized relevance assessment. The core component of CRAS is RARE for assessing the relevance of information items according to mobile users' contextual situations. RARE consists of the components of the rule parser, the query generator and the query evaluator. We have implemented RARE to realize the functionalities of parsing a set of rules, translating the rules to SPARQL queries, aggregating the relevance ratings for given message/user pairs and updating the cumulated ratings in the *information item* repository.

RARE supports the configuration of the behavior of CRAS by the specification of different sets of rules. In the next chapter, we will focus on the evaluation of CRAS on the basis of different use cases and rule sets.

Part V

Evaluation

Chapter 8

Evaluation of System Configurability

We have elaborated the formalism for expressing rules (MRRL) in Chapter 6 and the implementation of a corresponding rule engine (RARE) executing such rules in Chapter 7. In order to show the feasibility of our architecture CIDA (see Chapter 4), a rule-based system CRAS was implemented to decide which information is contextualized to the situations of police officers. CRAS was designed to be adaptable to different situations by the reconfiguration of different sets of MRRL rules executed by RARE. In order to investigate how CRAS could meet these requirements, we focus on evaluating the particular properties of CRAS in the following two chapters.

This chapter present the data construction and the evaluation of CRAS on the basis of certain use cases. At the beginning of this chapter, the questions to be addressed are raised. Then, we illustrate how information items and contextual information were constructed from the scenarios used in the study (see Chapter 3), according to our information item model and context model (see Chapter 5). Also, we explain how MRRL rules were defined for updating the relevance of information items in a given context. Next, we present our evaluation method. By the end this chapter, we present the evaluation results and discuss how these results can provide answers to the questions. The results in this evaluation study were published in (Hu et al., 2011a).

8.1 Introduction

Our the rule-based system (CRAS) contains RARE, which supports the reconfiguration of different rule sets and thus enables the behavior of CRAS to be adapted to different use cases. The evaluation of CRAS we implemented is an integral part of our research. The methods for system evaluation could be qualitative, quantitative, or some combination. Qualitative methods employ data in the form of: transcripts of open-ended interviews, written observational descriptions of activities and conversations, and analysis of responses to open-ended items on a questionnaire (Kaplan and Duchon, 1988), while quantitative methods produce data that can be aggregated and analyzed to describe and predict relationships

(Kaplan and Maxwell, 2005). In order to evaluate CRAS, we designed the questionnaire to collect relevance judgements from police officers based on certain scenarios and thus constructed a gold standard. CRAS was quantitatively evaluated with respect to the gold standard by two evaluation measures: the precision and recall that CRAS achieves on given use cases. The former one is used to assess the accuracy while the latter one is to assess the coverage.

The datasets as well as rule sets were constructed in the context of the evaluation. Each dataset, corresponding to a use case that describes a typical scenario, consists of a number of information items as well as context information. A use case could be considered as a forward or a backward one:

Forward use case: a case that has not been taken into account when defining the current rule sets.

Backward use case: a case that has been used to construct the current rule sets at some stage.

There is similarity having with machine-learning technology, where forward use cases corresponding to test data and backward use cases corresponding to training data. Note that we did not learn automatically rules here, but users explicitly defined rule sets based upon earlier use cases. A set of initial rules is engineered for dealing with a particular use case as a starting point. In order to deal with a forward use case which describes a new type of a scenario, the current rule set is extended incrementally in such a way that additional rules are always asserted on top of the current rules without changing the current ones. The relations between different types of rule sets are herein defined as follows:

$$\begin{aligned} Rul_{i+1} &= Rul_i \cup AddRul_{i+1}(i > 0) \\ Rul_1 &= InitialRul \\ InitialRul &= \textit{A set of rules developed for a certain use case as a starting point.} \\ AddRul_{i+1} &= \textit{An additional set of rules adapted to a forward use case.} \end{aligned}$$

To be applied in practice, CRAS was designed to have the following key properties:

Effectiveness. The system is able to select adequately relevant information given end-users' contexts by applying a set of initial rules.

Generic configurability. The system should have generic configurability in the sense that it can deal well with forward use cases by the specification of the current rule sets.

Adaptability. The system can be easily adapted to forward use cases by only adding a set of additional rules.

In order to demonstrate how (and if) CRAS has the above properties, CRAS was evaluated with respect to different configurations. The configuration of CRAS is defined as the specification of a given rule set on a certain dataset.

In this chapter, two datasets were constructed corresponding to the two scenarios – a car collision scenario and a fallen painter scenario – that were presented in Chapter 3. These domain-specific scenarios are reused to evaluate CRAS for two reasons:

- Representative datasets could be constructed based on these scenarios. These scenarios, defined in cooperation with police officers, enable us to approximate realistic settings in which several events with different emergency levels take place. Accordingly, the representative datasets could be constructed to check whether CRAS can distinguish relevant from irrelevant information.

- A gold standard could be defined based on these scenarios. The behavior of CRAS can be evaluated with respect to the gold standard consisting of relevance judgements provided by police officers.

This chapter is started by presenting the questions to be addressed from the evaluation in Section 8.2. The construction of datasets and rule sets is explained in Section 8.3. The evaluation modes, measures and configurations are presented in Section 8.4. The evaluation results summarized in Section 8.5 provide answers to the questions. Finally, the conclusions are discussed in Section 8.6.

8.2 Research Questions

From the evaluation study, we expect to find out answers to the following questions:

- **Q1: Can CRAS select adequately relevant information based on a set of initial rules?**

  The effectiveness of CRAS should be preliminarily evaluated by applying a set of initial rules on a certain dataset as a starting point.

- **Q2: Is CRAS generically configurable?**

  In order to tackle a potential criticism that the rules engineered for a given use case are probably over-fitted in the sense that they are not able to be applied in other cases, it is necessary to assess the generic configurability of CRAS by applying the current rule sets on forward use cases.

- **Q3: How can CRAS be adapted to forward use cases by incremental extension of rule sets?**

  The adaptability of CRAS should be evaluated by two steps. Firstly, the behavior of CRAS should be tested on the rule sets which were extended by adding additional rules specialized for the forward cases. Furthermore, in order to understand the interaction between those additional and the current rules, the influence of additional rules should be assessed by applying those extended rules sets on backward cases.

8.3 Data Construction

The construction of datasets and rule sets based on the scenarios is presented in this section.

8.3.1 Datasets Definition

In the study presented in Chapter 3, one targeted event as well as three other minor events taking place nearby constitute each of the two scenario. All involved subjects were asked to step into the role of police units who were dispatched to handle the targeted event (i.e. a car collision incident or a fallen painter incident). For each scenario, the contextual situation of police officers was described with reference to four specific phases. The main role of the subjects participated in the study was to assess whether a number of information items in a certain phase were *must know, nice to know* or *do not need to know*. The dataset was constructed for each scenario consisting of 25 information items as well as context information concerning five context dimensions (i.e. user, time, location, event and task). The datasets for the scenarios corresponding to a car collision and a fallen painter are denoted by D_c and D_p.

Information Item Representation. Consider that all messages received by the CCR in practice should be known its reporting time. Each information item was attached to a time stamp when we constructed it. In order to formalize these information items, the implicitly attributes were explicitly represented according to the information item model (see Chapter 5). These attributes capture facts about *what has happened*, *when* and *where*, *who are involved* in and *where information comes from*. Also, each information item was classified to a certain or multiple information categories to explain the types of information. Comparing the information items in D_c and D_p, eight of them represent the same facts since they describe the same ongoing events happening nearby. All information in each dataset was formalized by way of a total number of RDF triples: 590 triples in D_c and 610 triples in D_p.

To illustrate how information items are encoded in datasets, take one of them reporting the acts of a driver who has violated a red light for example: "*An emergency call is received at 22:06, 2010-01-01; a witness reports that a driver Kees involved in a car collision incident has violated a red light*." This message can be represented by RDF triples shown in Figure 8.1. These triples can be explained as:

```
PREFIX cd: <http://ruleEngine.org/contextData/ >

cd :DriverViolatingRedLightMsg
   a    cd :IncidentEvidence  ;
   cd :referenceID    "msg1"^^xsd:string  ;
   cd :reportedBy    cd :Witness  ;
   cd :reportTime    "2010-01-01T22:06:00Z"^^xsd:dateTime  ;
   cd :describedLoction       cd :CarCollisionEvent1Loc ;
   cd :describedObject  [
          cd :isInvolvedIn   cd :CarCollisionEvent1  ;
          cd :identification  "Kees"^^xsd:string  ;
          cd :hasBehavior   cd :ViolatingRedLight
     ] .
```

Figure 8.1: An Information Item Representation

- The corresponding message from a witness (infoSource) is *reported at* "22:06, 2010-01-01" (*reportTime*) from the spot of a car collision incident (*describedLocation*).
- It is *of type* incident evidence information (infoCategory).

- It describes a driver “Kees” (*describedObject*) who *is involved in* a car collision incident and this driver has violated a red light (*hasBehavior*).

Contextual Situation Representation. In each scenario, the evolving situation of police officers dispatched to handle a certain event is described by four consecutive phases: (1) departure; (2) arrival; (3) initial investigation; and (4) further investigation.

In the case of a car collision scenario, two cars are collided at the corner of Mekelweg and Stieltjesweg around 22:00 in Delft, Netherlands. Suppose that officers “Pieter” and “Wim” as members of a police unit are dispatched to deal with this incident. During the course of tackling this targeted event, three other events take place nearby: a wounded painter who has fallen down from the scaffolding; a woman who has been robbed and a confused old man who has lost his way. As the context model illustrated in Chapter 5, the contextual situation of a police officer can be represented by four context dimensions with reference to a specific phase. Let us consider that: “*at 22:20, police officer ‘Pieter’, who is in the phase of initial investigation, is continuing to administer a breathalyzer test for alcohol use for the two drivers involved in a car collision incident. While his colleague ‘Wim’ has just been involved in the phase of further investigation and is inspecting a car in which some suspect chemical substances are founded*.” In such a situation, the corresponding context information is represented by a set of RDF triples as Figure 8.2 shows. It can be explained as:

- “Pieter” and “Wim”, who are police officers (*hasRole*), are *targeted at* a car collision event and are *located at* the place where this event happened.

- “Pieter” is in the phase of initial investigation (*inPhaseOf*) and he *is engaged in* administering a breathalyzer test (*taskType*). His task, starting at “22:10:00, 2010-01-01” (*startTime*), is targeted at the driver “Jan” and “Kees” (*targetedObjects*).

- “Wim” is in the phase of further investigation (*inPhaseOf*) and he *is engaged in* inspecting a car (*taskType*). His task, starting at “22:20:00, 2010-01-01” (*startTime*), is targeted at the car “SZ-VB-69” (*targetedObjects*).

- A car collision event *targeted by* police officers “Pieter” and “Wim” *happens at* “22:20:00, 2010-01-01”. This targeted event is nearby three other events (*nearbyEvent*): a fallen painter incident, a handbag robbery as well as a lost old man event.

- The *spot of* this car collision incident is at “the corner of Mekelweg and Stieltjesweg” (*street*), “Delft” (*city*), “the Netherlands” (*country*). This location *is nearby* the locations of three other events.

8.3.2 Rule Sets Definition

For dataset D_c (the case of handling a car collision event), a set of initial rules was built denoted as Rul_c. In order to adapt to a new case of rescuing a fallen painter, an extended rule set denoted as Rul_{c+p} was developed for the dataset D_p by adding additional rules. Rul_c as an instance in the Rul_1 class and Rul_{c+p} as an instance in the Rul_{i+1} class are defined as follows:

```
PREFIX cd: <http://ruleEngine.org/contextData/ >

cd :PolicePieter
        cd :hasRole     cd :PoliceOfficer  ;
        cd :targetedAt    cd :CarCollisionEvent1  ;
        cd :isLocatedAt  cd :CarCollisionEvent1Loc  ;
        cd :inPhaseOf    cd :InitialInvestigation  ;
        cd :engagedIn   [
              cd :taskType  cd :AdministeringBreathalyzerTest  ;
              cd :targetedObject  (
                          cd :DriverJan
                          cd :DriverKees
                           )  ;
              cd :startTime      "2010-01-01T22:10:00Z"^^xsd :dateTime
        ].

cd :PoliceWim
        cd :hasRole        cd :PoliceOfficer  ;
        cd :targetedAt    cd :CarCollisionEvent1  ;
        cd :isLocatedAt  cd :CarCollisionEvent1Loc  ;
        cd :inPhaseOf    cd :FurtherInvestigation  ;
        cd :engagedIn   [
              cd :taskType   cd :InspectingCar  ;
              cd :targetedObject  [
                        cd :identification  "carSZ-VB-69"^^xsd:string
               ] ;
              cd :startTime      "2010-01-01T22:20:00Z"^^xsd :dateTime
        ].

cd :CarCollisionEvent1
        cd :isTargetedBy   (
                   cd :PolicePieter
                   cd :PoliceWilm
                   )  ;
        cd :nearbyEvent   (
               cd :RobberyEvent1
               cd :LostManEvent1
               cd :FallenPainterEvent1
               )  ;
        cd :happensAt         "2010-01-01T22:00:00Z"^^xsd:dateTime  ;
        cd :locatedAt          cd :CarCollisionEvent1Loc  .

cd :CarCollisionEvent1Loc
        cd :isSpotOf    cd :CarCollisionEvent1  ;
        cd :isNearby    (
               cd :RobberyEvent1Loc
               cd :LostManEvent1Loc
               cd :FallenPainterEvent1Loc
               )  ;
        cd :locName     [
               cd :country  "The Netherlands"^^xsd:string  ;
               cd :city        "Delft"^^xsd:string  ;
               cd :street     "the corner of the Mekelweg and the Stieltjesweg"^^xsd:string
               ].
```

Figure 8.2: Contextual Situation Representation

- Rul_c: consisting of **32** rules engineered for the dataset D_c.
- Rul_{c+p}: containing the rules from Rul_c in addition to **20** additional rules adapted to the dataset D_p.

Method for Extending the Rule Set. In order to extend the rule set, additional rules can be engineered with a modest effort. As for the 20 additional rules in Rul_{c+p}, 17 of them were built for specifying new types of information in dataset D_p, and the rest of them for refining the conditions of those rules already defined in Rul_c, such as adding some conditions to assess the spatio-temporal context.

For adapting to a forward use case, additional rules can be easily developed by reusing as well as modifying of triple patterns (i.e. *p(s, o)*) in the body of current rules, and also by specifying a desirable value to the head of those rules. Let us consider *medical history* information in the dataset D_p. The *medical history* of a victim described in the fallen painter scenario is a new information category which is not contained in the dataset D_c. But it has been known that there are rules in Rul_c for dealing with *criminal record* information which is also personal background like *medical history* information. On the basis of those rules, a set of additional rules for *medical history* information can be easily defined as the following steps:

1. Specifying the information category. Users need to choose an appropriate information category and specify a new class name (*e.g. MedicalHistory*) to a triple, such as "**infoType** ($?msg$, MedicalHistory)".
2. Reusing the triple patterns which specify the relations between the context dimensions. The triple patterns specifying the following relations can be reused to define additional rules, i.e. the relation of *described object* between messages ($?msg$) and involved persons ($?involPerson$), the relation of being *involved in* between involved persons and events ($?event$), the relation of being *targeted by* between events and users ($?user$), the relation of being *engaged in* between users and tasks ($?task$), and also the relation of *targeted object* between tasks and involved persons.
3. Combining the conditions in the rule body with the correct logical operators ($\&$ or $|$) and specifying a value in the rule head according to the requirements.

Following the above steps, the three rules specialized for *medical history* information in Rul_{c+p} were thus defined as:

- **infoType**($?msg$, MedicalHistory) & **describedObject** ($?msg$, $?person$) &
  isInvolvedIn ($?person$, $?event$) & **isTargetedBy**($?event$, $?user$) &
  engagedIn ($?user$, $?task$) & **targetedObject**($?task$,$?person$) &
  (**inPhaseOf**($?user$, Depature) | **inPhaseOf**($?user$, Arrival))
  $\Longrightarrow$
  updateRating (-1.0)
- **infoType**($?msg$, MedicalHistory) & **describedObject** ($?msg$, $?person$) &
  isInvolvedIn ($?person$, $?event$) & **isTargetedBy**($?event$, $?user$) &
  engagedIn ($?user$, $?task$) & **targetedObject**($?task$,$?person$) &

inPhaseOf($?user$, InitialInvestigation))
$\Longrightarrow$
updateRating $(+5.0)$

- **infoType**($?msg$, MedicalHistory) & **describedObject** ($?msg$, $?person$) & **isInvolvedIn** ($?person$, $?event$) & **isTargetedBy**($?event$, $?user$) & **engagedIn** ($?user$, $?task$) & **targetedObject**($?task$,$?person$) & **inPhaseOf**($?user$, FurtherInvestigation)
  $\Longrightarrow$
  updateRating $(+2.0)$

8.4 Evaluation

In this section, we present our evaluation method, modes and measures. Following our evaluation method, the behavior of CRAS was evaluated for the two rule sets on the two datasets as defined in Section 8.3 with respect to different configurations. For each configuration, the results of CRAS were measured in terms of precision and recall in two evaluation modes.

8.4.1 Evaluation Method

With the aim of addressing the questions raised in Section 8.2, our evaluation method is defined as follows:

1. We evaluated the effectiveness of CRAS by applying a set of initial rules to a certain scenario as a starting point.
2. We evaluated the generic configurability of CRAS by applying the current rule sets to forward use cases.
3. To investigate the adaptability of CRAS, we assessed the behaviour of the incrementally extended rule sets on forward use cases. Furthermore, we evaluated the influence of the additional rules for adapting CRAS to forward use cases on backward ones.

8.4.2 Evaluation Modes

The behavior of CRAS was evaluated with respect to the top-k (top-5 and top-10) information items retrieved in terms of Precision/Recall and F-Measure in two evaluation modes: (i) lenient and (ii) strict.

From our interview with domain experts, we learned that in practice police officers might be interested in only getting a small amount of *highly relevant* messages (e.g. in stress situations), while in other situations they might be interested in coverage. Therefore, the results were evaluated with respect to the top-5 and top-10 retrieved items.

- In strict evaluation mode, we regard only items rated as *highly relevant* – with a rating of no less than $+3.5$ – according to the gold standard as correct (yielding the set GS_{strict}).

- In lenient evaluation mode, we regard all *relevant* items rated with no less than $+2.0$ as correct (yielding the set $GS_{lenient}$).

Due to fact that the end-users' requirements for what information is relevant depend on the specific phases they are in, the number of relevant information items varies in each phase per scenario. The cardinality of the gold standard in the two scenarios is shown in Table 8.1.

In the Car Collision Scenario				
Relevance	Phase 1	Phase 2	Phase 3	Phase 4
Highly Relevant	6	4	4	2
Relevant	9	9	10	9
Irrelevant	16	16	15	16
In the Fallen Painter Scenario				
Highly Relevant	4	2	2	2
Relevant	10	8	9	9
Irrelevant	15	17	16	16

Table 8.1: The Cardinality of the Gold Standard in the Two Scenarios

8.4.3 Evaluation Measures

Precision denotes the ratio of correctly retrieved information items over all retrieved items (top-5 or top-10). Recall quantifies the ratio of correctly retrieved information items over all relevant items in a gold standard (GS_{strict} or $GS_{lenient}$). Also, F-Measure is the harmonic mean of precision and recall. As CRAS delivers information tailored to the particular phase of end-users, we computed the above values per phase and further averaged them for four phases per scenario. Precision and recall and also F-Measure are defined as the following formulas ($\alpha \in \{\textit{strict, lenient}\}, k \in \{5, 10\}$):

$$P_\alpha@k = \frac{|Top\text{–}k \cap GS_\alpha|}{k}, \tag{8.1}$$

$$R_\alpha@k = \frac{|Top\text{–}k \cap GS_\alpha|}{|GS_\alpha|}, \tag{8.2}$$

$$F_\alpha@k = 2 \times \frac{P_\alpha@k \times R_\alpha@k}{P_\alpha@k + R_\alpha@k}. \tag{8.3}$$

8.4.4 Configurations

In this chapter, CRAS was evaluated for two rule sets on two datasets with respect to the following configurations:

1. In order to demonstrate the performance of CRAS on a set of initial rules in terms of accuracy and coverage, the rule set Rul_c was applied to the corresponding dataset D_c.

2. To investigate whether the rules developed for a specific scenario can provide a base performance for a forward case, the performance of rule set Rul_c was evaluated on dataset D_p.

3. To evaluate whether CRAS can be adapted to a forward use case by only adding additional rules, the extended rule set Rul_{c+p} was applied to the dataset D_p.

4. With the goal of assessing the influence of additional rules on a backward case, the rule set Rul_{c+p} was applied to the dataset D_c.

8.5 Results

The results of CRAS with regard to the two rule sets and the two datasets are shown in Tables 8.2 and 8.3. The results show precision, recall and F-Measure values for the different evaluation modes: top-5 vs. top-10 and strict vs. lenient. In order to demonstrate how the behavior of CRAS varies for each phase, all results for each phase are presented in Table 8.2. To assess the overall performance of CRAS, the average values of the precision and recall and also F-Measure for four phases per scenario are shown in Table 8.3. The performance of CRAS is compared to that of the two baselines as represented in Table 8.5.

		Rul_c											
Eval. Mode		**Strict**						**Lenient**					
	Phase	P@5	R@5	F@5	P@10	R@10	F@10	P@5	R@5	F@5	P@10	R@10	F@10
D_c	1.	1.00	0.83	0.91	0.60	1.00	0.75	1.00	0.56	0.71	0.80	0.89	0.84
	2.	0.80	1.0	0.89	0.40	1.00	0.57	1.00	0.56	0.71	0.70	0.78	0.74
	3.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.50	0.67	0.90	0.90	0.90
	4.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.44	0.57	0.90	1.00	0.95
D_p	1.	0.40	0.50	0.44	0.25	0.50	0.33	0.40	0.20	0.27	0.25	0.20	0.22
	2.	0.40	1.00	0.57	0.20	1.00	0.33	0.60	0.38	0.46	0.40	0.50	0.44
	3.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.44	0.57	0.40	0.44	0.42
	4.	0.20	0.50	0.29	0.11	0.50	0.18	0.60	0.33	0.43	0.33	0.33	0.33
		Rul_{c+p}											
D_c	1.	1.00	0.83	0.91	0.60	1.00	0.75	1.00	0.56	0.71	0.70	0.78	0.74
	2.	0.60	0.75	0.67	0.40	1.00	0.57	0.80	0.44	0.57	0.70	0.78	0.74
	3.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.50	0.67	0.90	0.90	0.90
	4.	0.40	1.00	0.57	0.20	1.00	0.33	1.00	0.56	0.71	0.70	0.78	0.74
D_p	1.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.50	0.67	0.90	0.90	0.90
	2.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.50	0.62	0.70	0.88	0.78
	3.	0.40	1.00	0.57	0.20	1.00	0.33	1.00	0.56	0.71	0.70	0.78	0.74
	4.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.44	0.57	0.90	1.00	0.95

Table 8.2: The Overall Evaluation Results

8.5.1 Baselines

The two baselines are defined here with respect to the phase that a user is in and the event that a user is targeted at.

	Rul_c						
	Eval. Mode	P@5	R@5	F@5	P@10	R@10	F@10
D_c	**Strict**	0.70	0.90	0.76	**0.40**	**1.00**	0.56
	Lenient	**0.95**	**0.51**	0.67	0.83	0.90	0.86
D_p	**Strict**	0.35	0.75	0.47	**0.19**	**0.75**	0.30
	Lenient	**0.60**	**0.34**	0.43	0.35	0.37	0.36
	Rul_{c+p}						
D_c	**Strict**	0.65	0.83	0.70	**0.40**	**1.00**	0.56
	Lenient	**0.95**	**0.51**	0.67	0.75	0.81	0.78
D_p	**Strict**	0.45	0.94	0.60	**0.25**	**1.00**	0.39
	Lenient	**0.90**	**0.50**	0.64	0.80	0.89	0.84

Table 8.3: The Average of Evaluation Results

Phase-specific Baseline. From the study presented in Chapter 3, the information needs of police officers involved in specific phases in the two scenarios were intuitively summarized. Accordingly, a phase-specific baseline is defined: selecting given types of information for a user who is involved in a specific phase. Table 8.4 illustrates which categories of information are possible relevant to a user in a given phase.

Phase	**Relevant**	
	Highly Relevant	**Others**
1	navigation; personal safety; criminal record.	priority activity; attributes of nearby incidents; medical history.
2	priority activity; personal safety; medical history.	attributes of nearby incidents; criminal record.
3	personal safety; incident evidence; criminal record; medical history.	attributes of nearby incidents; priority activity; social relations; personal background.
4	incident evidence; personal safety; criminal record.	priority activity; attributes of nearby incidents; social relations; personal background.

Table 8.4: Phase-specific Baseline

By evaluating the queries corresponding to those roughly estimated phase-specific information needs, two sets of information items are yielded: one set consists of all *relevant* information and another one only consists of *highly relevant* one. By randomly choosing k ($k \in \{5, 10\}$) information items from these two sets respectively and comparing those selected items with the gold standard in terms of precision and recall, the results of the phase-specific baseline can be measured ($Baseline_{phase}$). In order to get a realistic estimation, choosing k information items randomly was proceeded 100 times. The results yielded by $Baseline_{phase}$ shown in Table 8.5 are the average of those 100 values.

Event-specific Baseline. Given that police officers need information that can support them in handling targeted events, an event-specific baseline is defined as: choosing information which is relevant to the *targeted events* and also the *objects* involved in those events.

Let us consider the car collision scenario, police offices are handling a car collision incident (*targeted event*) and this event involves two drivers and cars (*objects*). The event-specific baseline can be defined as: selecting the information for these police officers, which is relevant to that car collision incident and also two involved drivers as well as their cars. Using the same method for measuring the results of the phase-specific baseline, the results yielded by the event-specific baseline are also evaluated with respect to the gold standard as shown in Table 8.5.

		Eval. Mode	P@5	R@5	F@5	P@10	R@10	F@10
D_c	CRAS on Rul_c	Strict	0.70	0.90	0.76	**0.40**	**1.00**	0.56
		Lenient	**0.95**	**0.51**	0.67	0.83	0.90	0.86
	$Baseline_{phase}$	Strict	0.41	0.44	0.37	**0.40**	**0.87**	0.54
		Lenient	**0.56**	**0.30**	0.36	0.56	0.61	0.57
	$Baseline_{event}$	Strict	0.29	0.31	0.24	**0.26**	**0.60**	0.34
		Lenient	**0.41**	**0.22**	0.26	0.41	0.43	0.41
D_p	CRAS on Rul_{c+p}	Strict	0.45	0.94	0.60	**0.25**	**1.00**	0.39
		Lenient	**0.90**	**0.50**	0.64	0.80	0.89	0.84
	$Baseline_{phase}$	Strict	0.26	0.50	0.26	**0.25**	**0.89**	0.37
		Lenient	0.57	**0.32**	0.39	**0.59**	0.65	0.61
	$Baseline_{event}$	Strict	0.20	0.42	0.19	**0.18**	**0.80**	0.30
		Lenient	0.32	0.18	0.20	**0.35**	**0.35**	0.33

Table 8.5: The Results Comparison between the Baselines and CRAS

8.5.2 Answers to Research Questions

From the results shown in Tables 8.3 and 8.5, the three questions raised in Section 8.2 can be answered.

Firstly, in order to address Q1, CRAS was evaluated by applying a set of initial rules developed for a specific scenario on the corresponding dataset. The results in Table 8.5 show that:

1. At top-5, the precision is between 0.70 and 0.95 while the recall is between 0.51 and 0.90. Compared to the two baselines shown in Table 8.5, it can be seen clearly that the precision of CRAS achieves outperforms the precision of $Baseline_{phase}$ ranging from 0.41 to 0.56. Also, the precision of CRAS significantly outperforms that of $Baseline_{event}$ ranging from 0.29 to 0.41. In addition, the recall achieved by CRAS is improved compared to the recall of $Baseline_{phase}$ between 0.30 and 0.44 and also compared to that of $Baseline_{event}$ between 0.22 and 0.31.

2. At top-10, the precision ranges from 0.40 to 0.83 and the recall ranges from 0.90 to 1.00. Compared to the precision of $Baseline_{phase}$ between 0.40 and 0.56 and also that of $Baseline_{event}$ between 0.26 and 0.41, it can be seen that CRAS has improved the accuracy. Moreover, CRAS has enhanced the coverage, given that the recall in lenient mode is improved from 0.61 ($Baseline_{phase}$) / 0.43 ($Baseline_{event}$)

to 0.90 and the recall in strict mode is enhanced from 0.87 ($Baseline_{phase}$) / 0.60 ($Baseline_{event}$) to 1.00.

From the above analysis, we can arrive at the conclusion that:

- CRAS can be configurable such that it is precise enough to select adequately relevant information by applying a set of initial rules.

Secondly, Q2 can be addressed by evaluating the performance of the current rule set on a forward scenario. The results in Table 8.3 demonstrate that:

1. The precision of the rule set Rul_c achieves for a forward case D_p is between 0.19 (P@10, strict) and 0.60 (P@5, lenient). Compared to the event-specific baseline (see Table 8.5) that yields the precision between 0.18 and 0.35, Rul_c provides a reasonable performance.

2. The recall of the rule set Rul_c achieves for a forward case D_p ranges between 0.34 (R@5, lenient) and 0.75 (R@10, strict). This result is also comparable to the recall between 0.18 and 0.80 given by the event-specific baseline.

From the above results, we can conclude that:

- The rules developed for a particular use case are not over-fitted and thus show the generic configurability of CRAS.

Thirdly, in order to investigate Q3, an incrementally extended rule set was not only applied to a forward scenario but also to a backward one. We can observe from that:

1. In the case of applying the rule set Rul_{c+p} to the dataset D_p, the precision ranges between 0.25 (P@10, strict) and 0.90 (P@5, lenient) as well as the recall ranges between 0.50 (R@5, lenient) and 1.00 (R@10, strict). Compared to the results yielded by the phase-specific baseline (see Table 8.5), both of the precision and recall are enhanced: the best-case of precision is improved from 0.59 to 0.90 and the best-case of recall is improved from 0.89 to 1.00.

2. By applying the extended rule set Rul_{c+p} to dataset D_c, the precision is between 0.40 (P@10, strict) and 0.95 (P@5, lenient) as well as the recall is between 0.51 (R@5, lenient) and 1.00 (R@10, strict). Comparing the results of rule set Rul_{c+p} to Rul_c on the same dataset D_c, it can be seen that the results at top-10 (strict) and at top-5 (lenient) remain the same, while those additional rules only slightly reduce the F-Measures from 0.76 to 0.70 (F@5, strict) as well as from 0.86 to 0.78 (F@10, lenient).

We thus can conclude from the above observations that:

- CRAS can be adapted to a forward scenario easily by only adding additional rules.
- The addition of rules gradually improves the behavior of CRAS on a forward scenario while not significantly degrading the performance on a backward use case.

8.6 Conclusion

In this chapter we evaluated our rule-based system based on different scenarios with respect to the gold standard determined in cooperation with police officers. With the goal of addressing the three questions, the datasets as well as rule sets were constructed based on two realistic scenarios and the evaluation method was defined. With respect to different configurations, the behavior of CRAS was evaluated in terms of precision and recall in two evaluation modes (strict & lenient).

The evaluation results have provided answers to the three questions we posed. First, by applying a set of initial rules on the corresponding dataset, the results demonstrate that the performance of CRAS outperforms that of the two baselines and thus can verify that CRAS it is able to precisely select adequate information tailored to the information needs of end-users in a given phase. Second, by applying the current rule set on a forward case, the results show that the rules engineered for a particular use case are not over-fitted and thus show the generic configurability of CRAS. Third, by applying an incrementally extended rule set on a forward use case, the results corroborate that CRAS can be adapted to a forward case easily by only adding additional rules. Moreover, the addition of rules gradually improves CRAS, corroborated by the fact that the extended rule set provides a comparable performance on a forward case while not significantly degrading the performance on a backward case.

Although rule-based systems are often criticized for being monolithic systems that only perform adequately for rather static datasets (Wang et al., 2004), our evaluation has verified that CRAS can be adapted to different use cases with a modest effort. Our results cater for the conclusion that rule-based implementations are feasible for highly dynamic context-aware services (Costa et al., 2007). In summary, the precision and recall levels achieved by CRAS are satisfactory and corroborate the effectiveness of our approach. Hence, our evaluation leads to the major conclusion that CIDA is applicable in practice.

However, one clear limitation is that CRAS is only tested on a limited number of datasets: two related use cases consisting of fifty information items and a number of context information. We cannot conclude that CRAS could perform very well on a completely different use case without any relation with the current cases by applying current rules sets. But we are confident that the evaluation results have corroborated the feasibility of our approach, given that CRAS has been evaluated on the realistic and representative datasets in a quantitative method.

In order to further investigate the generic configurability and in particular the adaptability of CRAS, we need to apply CRAS on a different use case and to generalize implications from the results. We also need to investigate how can CRAS be adapted to a forward case without relying on collecting relevance judgements. In the next chapter, we will present the evaluation on the adaptability of CRAS based on a different user case.

Chapter 9

Evaluation of System Adaptability

In the previous chapter, we evaluated CRAS following our evaluation method based on two use cases. The results provided answers to the three questions. In order to tackle the limitation that those results are based on a limited number of datasets, in this chapter CRAS is further evaluated in particular on its adaptability to different use cases. The evaluation results were published in (Hu et al., 2011b).

9.1 Introduction

An evaluation of CRAS in Chapter 8 has demonstrated that precision and recall levels are satisfactory compared to the two baselines. In this chapter, we further investigate the generic configurability and the adaptability of CRAS (see Q2 and Q3 raised in Chapter 8) by evaluating it on a different use case without any relation with the current ones. In particular, two sub-questions were derived in order to further address Q3. These questions are listed as follows:

- **Q2: Is CRAS generically configurable?**
- **Q3.1: Is it possible to adapt CRAS to forward use cases without relying on an already known set of relevance judgments?**
- **Q3.2: How the additional rules that adapt CRAS to forward use cases influence the behavior of CRAS on backward use cases?**

With the goal of evaluating CRAS on a different use case, firstly, we consulted domain experts and collected a new realistic scenario. The findings from the interview not only guided us to construct a case of a *domestic violence scenario* with a number of information items, but also helped us to reflect on our approach for designing a study. Then, we carried out the study in cooperation with police officers who provided their relevance judgements for information items in given phases of this scenario. Finally, CRAS was evaluated on this use case with respect to the gold standard constructed from the study.

Q3.1 is addressed by developing rules adapted to a forward use case in different strategies. Instead of engineering the rules after the collection of end-users' relevance judgements as we did before, one rule set was extended by adding additional rules without requiring the relevance judgements from end-users explicitly, that is so-called *scenario-based* rules. Whereas another extended rule set was built by the modification of the first set according to the relevance judgements, i.e. *rating-based* rules. The adaptability of CRAS was evaluated for these two rule sets on the same scenario.

This chapter is structured as follows. We introduce how a new scenario was constructed and a study was designed in cooperation with domain experts in Section 9.2. In Section 9.3 we present the results of that study in terms of a gold standard and the qualitative findings. We illustrate how we constructed the datasets as well as the rule sets in Section 9.4. Next, we discuss the evaluation results in Section 9.5. Finally, we present the conclusions in Section 9.6.

9.2 Study Design

With the goal of identifying the information needs of end-users in the context of a new scenario, we interviewed domain experts to collect a new scenario and also their comments on our approach for designing a study. Next, we created a questionnaire consisting of a new scenario and a number of information items constructed in cooperation with those domain experts. Lastly, we performed a questionnaire-based study in which several police officers were participated.

9.2.1 Interview

For collecting a new and realistic scenario, we consulted domain experts and took their domain-specific knowledge into account for constructing a use case. The interview was conducted in October, 2010, in the Multi Disciplinary Innovation Technology (M-DO-IT) Center run by the vtsPN. With the help of our project manager in vtsPN, we interviewed two domain experts for approximately two hours. Both of the experts were former police officers and now working at the M-DO-IT center. Detailed written notes were taken during the interview, which were transcribed within one day and then returned to the project manager for review and correction.

Purpose. The interview was conducted with two purposes:

1. To obtain new and realistic scenarios together with a specification of the information police officers needed for their actions when involved in these scenarios.
2. To reflect on our approach for designing a study for identifying the information needs of police officers.

Procedure. Considering the above objectives, the interview was conducted involving three phases: (1) presentation, (2) brainstorming, and (3) reflection.

1. Presentation. The introduction of our objectives.

   We firstly presented our specific research goal in the context of the MOSAIC project, and then we illustrated how our system could support decision-making for police officers by contextualized information delivery. We explained our main objective, i.e. collecting a realistic scenario which can describe the activities of police officers for dealing with "small" scale incidents (routine events) in daily mobile police work. To avoid biasing experts on providing scenarios, at this phase we did not introduce our existing scenarios. Also, we listed several questions which were also expected to be answered through the interview:

- Q1. What are the available information sources for the CCR in practice?
- Q2. What are the characteristics of the working environment of police officers?
- Q3. How do police officers get information in practice for handling the incidents?
- Q4. What information is critical for police officers to perform their tasks?

2. Brainstorm. The collection of answers and scenarios.

   Targeting the above questions, the domain experts provided their answers. They also proposed several realistic scenarios, i.e. the cases of the *alcohol testing of drivers*, the *suspected car checking*, and also the *domestic violence event handling*.

3. Reflection. The selection of the most appropriate scenario and the collection of comments.

   After a brief explanation about how we performed an information needs study based on certain scenarios, we discussed with the experts about the most appropriate use case we should choose. By considering the criteria that a new scenario should be significantly different than those backward ones, experts suggested us to choose the case of a *domestic violence incident involving a woman who is attacked by her drunken boyfriend*. In the context of this scenario, we explicitly asked the question "*Which information could be received by police officers for dealing with such a domestic violence event?*" In addition, the experts also commented on our approach for collecting the information needs.

9.2.2 Answers and Comments

We summarize the answers from domain experts to the four questions during the interview and also their comments.

- The answers to Q1 confirm the available sources which could be used to capture the context information in our rule-based system.

  As the experts pointed out, the Gemeenschappelijk Meldkamer Systeem (Common Communications Center System, GMS) is the central police system, which is used for handling 112 emergency calls and has a "search around" function for finding police officers busy with a low priority incident. Other systems connected with the GMS system provide additional information, for example, the C2000 mobile digital communication system[1] and the CityGIS (GPS) system which can track the location of police car on a map. Besides, the standard databases such as the criminal records database also provide background information for police officers.

[1] www.c2000.nl,2007

- The answers to Q2 characterize the situations police officer might encounter while working which are unforseen and hard to prepare for.

  The experts stated that a routine situation could be at any given time evolve into an urgent one. Let consider two examples they provided, one is that *a police officer stopped a car and tried to administer a breathalyzer test for the driver; he did not notice that he was in a dangerous situation since one passenger was holding a gun hidden by a newspaper*. Another case is that police officers think they have already controlled the situation, but some unexpected things happen which scale up the urgency level. For example, *a crowd surrounded a police officer who was trying to take away a drunken person*.

- From the answers to Q3, we learned how police officers obtain information in routine as well as urgent situations. The answers also support our assumption that in stress situations end-users might be interested in only getting a small amount of highly relevant information (see Section 8.4.2).

  In a routine situation, police officers can log in the system (e.g. GMS) to input information relevant to their targeted events, and also to retrieve information, including personal background concerning the objects involved in those targeted events. Whereas in an urgent situation, such as a violence incident involving injured victims, police officers should take actions under time pressure. While driving to an incident spot, they get information through the equipment in their car which can show a map and relevant information. After leaving the car, they mainly communicate orally with the CCR or other colleagues in the same group.

- The answers for the critical information supporting for task execution (Q4) summarize the important facts from different information sources, and those facts are in line with the dimensions represented in our information item model (see Chapter 5).

  The experts summarized that police officers need information which can help them get overview of the situation they will get involved. Such information can answer "Seven WH-questions" (Erteschik-Shir, 1986), i.e. when, where, which, how, what, who and why. In particular, the experts stated that: "The information concerning the safety of responders is very important because every responder wants to go home alive without injuries."

- Comments. In general, the domain experts approved that our application is able to support police officers in decision making. Also, they approved that our approach for identifying the information needs of police officers in given scenarios is feasible and the description of the contextual situations with reference to certain phases is understandable.

  Meanwhile, they also pointed out that two of our assumptions in the description of the used scenarios are not totally realistic. One assumption is that police officers always are ready to read the messages shown on their PDA even if they are busy with executing their task in an urgent situation. However, according to the experience of these domain experts, policemen not only want to read the raw data from the mobile data terminal (MDT), they also appreciate to hear the emotion in the voice of the dispatcher in the CCR. Another assumption is that in the fallen painter scenario police officers are expected to arrive at the incident spot in the first place before the fire bridge and ambulance in order to rescue an injured victim. Nevertheless, the domain experts clarified that in practice policemen will be the third party to arrive.

9.2.3 Obtained Scenario

A scenario of domestic violence obtained from the interview can be summarized as follows: *A 40-year-old woman - "Marijke"- calls 112 and asks for help. She says that her boyfriend "Freek" is drunk and hit her head with a bottle 10 minutes ago. Marijke is further interviewed according to the Seven WH-questions and advised to ensure her safety.* The evolving situation of a police unit that is dispatched to handle this event is described by four consecutive phases and explained in the following:

1. In the phase of departure, police officers are driving to the location of Hulzenberg 25 in Delft at 18:02. They have been briefed about a victim and an offender who is drunk and behaves violently by the CCR.
2. After arriving at 18:15, the police officers find that the offender "Freek" is too drunk to be interviewed. They decide that one officer will interview the victim "Marijke" and other colleagues will inspect the living room regarding traces of an obvious recent fight.
3. An initial investigation starts at 18:20, a police officer reports to the CCR that the victim "Marijke" needs a refuge after the interview. Other colleagues find that the apartment contains clues regarding illegal activities and thus they ask for assistance from the inspection department for a further investigation of the apartment.
4. In the phase of further investigation, the police officers take the victim "Marijke" and the offender "Freek" to the police station for further interrogation. Another inspection team starts gathering evidence at 18:35.

9.2.4 Estimated Information Needs for the Scenario

In the context of handling a domestic violence event, the domain experts raised several questions that could be important for police officers involved in this event to learn the situation. Those questions listed in the following helped us to estimate which information from different sources probably could help police officers to perform their task.

From the 112 calls, police offices are concerned with questions such as:

- Who called 112 to report this event?
- Where did the call come from? (e.g. on the street, or from the neighborhood)
- What did happen? (e.g. fighting, noisy, or quarreling)
- Why did it happen? (e.g. cause or motivation)
- Are the involved subjects armed? (e.g. weapon, knife, or gun)

- When was it seen by witnesses? (e.g. just now, or after the situation already be normal/quite)
- How is a crime in progress? (e.g. threats, shouting, or furniture breaking)

From the oral communications with the CCR, police offices would like to know:

- What do they need to do in order to handle the events?
- Do they have permission to investigate new findings?

As for background information, police officers need to have answers to questions such as:

- Is there any background information about the neighborhood they are entering?
- Is the person they are approaching dangerous?
- Has the suspect/victim been involved previously in domestic violence events?
- Does suspect/victim have any known mental illnesses?
- What are recent phone calls made by the suspect/victim?

9.2.5 Questionnaire Design

Questionnaire Structure. As the same structure used in the study presented in Chapter 3, a questionnaire was designed consisting of an introduction and a scenario with a number of information items and also the open questions. The scenario describes a domestic violence event as domain experts suggested; a number of information items consist of those messages that could provide answers to the questions listed in Section 9.2.4 and also irrelevant ones ("noise") added deliberately. Each item was expected to be judged with its relevance in specific phase as (1) must know, (2) nice to know, and (3) don't need to know. Next to the questions asking for a relevance judgement for an information item, we also asked the reason for rating its relevance. Besides, at the end of questionnaire, the two open questions are listed to further collect the information needs as:

- Do you think the information items that you rate from the list are enough to help your task actions? If not, can you list other relevant items in the specific situation?
- Can you give the reasons when you rate the information items as *must know*?

Information Items Definition. Although we learned through personal communication with police officers that in practice the number of information items could reach the order of thousands of items, we sketched 45 information items for the following reasons: (1) as police officers only could devote a limited time to our study, we should restrict the number of information items, so that the task of providing relevance judgments was feasible for police officers involved in our study; (2) we focus on a routine event such as a domestic violence event, so the number of information items could be relatively small in such a context; and

(3) the information items we chose are representative for typical types of information. Then, we asked the domain experts to determine whether the description of the scenario as well as the information items we sketched were relatively realistic. The reviewers pointed out that:

1. The number of information items was still too much for police officers to judge their relevance.

2. There were five unrealistic information items since it is impractical for the CCR to obtain them.

3. Some information items could be classified in the same category were listed next to each other.

According to the above comments, the modifications we did were:

1. Removal of some personal background information which is too detailed and thus can not be captured by the CCR in reality, for example, the fact that the victim "Marijke" has just lost her job two weeks ago.

2. Deletion of some information items which describe similar facts that were repeated several times.

3. Evenly redistribution of information items such that those could belong to the same category are evenly distributed.

After a few revisions we finalized the domestic violence scenario with 33 information items. Among these items, there are 8 items that were intentionally added as "noise", for instance, "*offender Freek owns a car with license plate 11-AAA-1*"; there are 5 items that explain the nearby events and thus are irrelevant to the targeted event.

Estimation for the Number of Relevant Information Items Per Phase. In order to balance the number of information items that could be relevant in four different phases, we asked the domain experts to estimate the relevance of information items depending on given phases. According to their estimation, the number of items that are probably relevant for police officers who are in a given phase is listed as: 22 items in the phase of departure; 13 items in the phase of arrival; 17 items in the phase of initial investigation; and 13 items in the phase of further investigation.

New Information Categories. In the two use cases, all 50 constructed information items could be classified into the 9 information categories (see Section 3.1), and the same categories can also be applied to the 33 information items in the case of the *domestic violence event*. However, those nine categories cannot address all of the questions listed in Section 9.2.4). In order to describe those information attributes did not include in the used scenarios, the corresponding new information categories are defined as follows:

- Phone call record. For example, "After calling 112, Marijke has made three additional phone calls". Such type of information could answer the question: "*What are recent phone calls made by the suspect/victim?*"

- The record for recidivist crimes. For instance, "Freek is on probation for an earlier assault on Marijke", and "an investigation is running on Freek having beaten a child living at the Hulzenberg 26, Delft." These information items could answer the question: "*Has the suspect/victim been involved previously in domestic violence events?*"

- Neighborhood background information, such as "5% of the apartment complex at the Hulzenberg is unoccupied". It could answer the question: "*Is there any background information about the neighborhood they are entering?* "

- Ongoing criminal behavior. It could answer the question: "*How is a crime in progress?*" An example of such information is that "a witness reports that from the window he saw a man was holding a women by the throat."

9.2.6 Study Setup

With the goal of collecting relevance judgements from police officers, we conducted a study in the context of the domestic violence scenario.

Participant Background. With the help of our project manager, we enrolled police officers from vtsPN as participants in our study. The project manager also e-mailed the questionnaire with an introduction in Dutch to the 14 police chief officers in Rotterdam-Rijnmond Region. Finally, we got 7 Dutch police officers involved in this study; five of them personally participated in the study and the other two chief officers replied to the e-mailed questionnaire.

All seven participants are male and experienced police officers who did not participant in our previous user study before. Five of them have more than 7 years working experience within police organizations.

Procedures. Each participant directly judged the relevance of 33 information items in four specific phases in the domestic violence scenario. Also, everyone provided answers to the two open questions. During the study, every participant clearly knew their task and did not have difficulty to provide their answers.

9.3 Results from the Study

Following the same method for measuring the relevance judgements presented in Chapter 3 (see Section 3.3.1), we averaged the relevance ratings of each information item in 4 phases as given by 7 police officers. Accordingly, we defined a gold standard and also obtained the qualitative findings.

9.3.1 Gold Standard

By the analysis of relevance judgements on all information items (see Section 3.3.1), a gold standard can be defined. The cardinality of the gold standard is shown in Table 9.1.

The Cardinality of the Gold Standard				
Relevance	Phase 1	Phase 2	Phase 3	Phase 4
Highly relevant	11	7	3	4
Relevant	16	14	11	12
Irrelevant	17	19	22	21

Table 9.1: The Cardinality of the Gold Standard in the Domestic Violence Scenario

9.3.2 Qualitative Findings

The qualitative findings following the user study are illustrated below.

- As for the answers to the first open question, all police officers participated in our study confirmed that the information items they rated as *relevant* in the questionnaire can help their actions. Besides, some of them also listed other relevant information that is summarized as follows:

  1. It is important to notify police officers about whether there would be some assistance from other colleagues for handling their targeted event.
  2. Police officers need to know when assistance from whom would be available. In the domestic violence scenario, after asking for assistance for a further investigation of the apartment, the police unit needs to be aware that with whom they would collaborate.

- From the answers to the second open question, it can be seen that information concerning the safety of police officers is very important. In particular, the respondents stated that the approaching officers must know the level of danger of the situation including the risk of getting attacked. They also pointed out that police officers involved in the domestic violence scenario need to know if there are young children at the spot, who for example might be held as hostages.

- According to the feedback from the participants (also in the discussion in a plenary debriefing session), all of them confirmed that the information needs of police officers vary in the four phases that were described in the scenario. They also provided some basic criteria for judging the relevance: (1) in the phase of departure (phase 1), police officers must know any information could help them arrive at the spot of incident quickly and safely. (2) After arriving (phase 2), they require the information that could help them to develop their action plan and also to ensure their safety. (3) In the phase of initial investigation (phase 3), they demand the information that could support them in investigating the targeted objects while avoiding potential threats to their safety. (4) When further investigating targeted objects (phase 4), they need the information to help them to collect evidences.

9.4 Data Construction

The construction of one dataset and two sets of rules based on the domestic violence scenario is presented in this section.

9.4.1 Datasets Definition

Information Item Representation. For the case of domestic violence scenario, the dataset D_v was constructed, consisting of 32 information items (messages) and the corresponding context information. All information was formalized by way of a total number of 900 RDF triples.

To illustrate how information items were formalized relying on our *information item model* (see Chapter 5), let us consider a message reporting the acts of violence of an offender. Figure 9.1 represents this message by the RDF triples which can be explained as:

- The corresponding message *reported by* a witness (infoSource) is reported at "20:00, 2010-01-01" (*reportTime*) from the location of an event (*describedLocation*).
- It would be *of type* personal safety (infoCategory) and also be *of type* incident evidence (infoCategory).
- It describes an offender (*describedObject*) named "Freek" (*identification*) who *is involved in* a domestic violence event and has acted violence (*hasBehaviour*).

```
PREFIX cd: <http://ruleEngine.org/contextData/ >

cd :OffenderViolenceBehaviorMsg
   a    cd :PersonalSafety;
   a    cd :IncidentEvidence;
   cd :referenceID  "msg2"^^xsd:string ;
   cd :reportedBy    cd :Witness  ;
   cd :reportTime    "2010-01-01T20:00:00Z"^^xsd:dateTime  ;
   cd :describedLocation  cd:DomesticViolenceEvent1Loc  ;
   cd :describedObject    [
          cd :isInvolvedIn    cd :DomesticViolenceEvent1  ;
          cd :identification     "Freek"^^xsd:string;
          cd :hasBehavior   cd :Violence ;
     ] .
```

Figure 9.1: Message Representation

Contextual Situation Representation. The context information which describes the relevant aspects of a user's current situation was also formalized in the *situational data model* (see Chapter 5). Supposed that police officer "Jan", who is targeted at a domestic violence event, is engaged in the task of gathering evidence, then his contextual situation can be represented in Figure 9.2 and is explained as:

- "Jan", who is a police officer (*hasRole*), is *targeted at* a domestic violence event and *is located at* the place where this event happens.
- "Jan" is *in the phase of* further investigation and he *is engaged in* gathering evidence (*taskType*). This task, starting at "20:20:00, 2010-01-01" (*startTime*), *is targeted at* the offender "Freek" and the victim "Marijke" (*targetedObjects*).

```
PREFIX cd: <http://ruleEngine.org/contextData/ >

cd :PoliceJan
        cd :hasRole     cd :PoliceOfficers  ;
        cd :targetedAt    cd :DomesticViolenceEvent1  ;
        cd :isLocatedAt  cd :DomesticViolenceEvent1Loc  ;
        cd :inPhaseOf    cd :FurtherInvestigation  ;
        cd :engagedIn   [
              cd :taskType  cd :GatheringEvidence  ;
              cd :targetedObject  (
                          cd :VictimMarijke
                          cd :OffenderFreek
                          )  ;
              cd :startTime       "2010-01-02T20:20:00Z"^^xsd :dateTime
        ].

cd :DomesticViolenceEvent1
        cd :isTargetedBy     cd :PoliceJan  ;
        cd :involvedObject   (
                        cd: VictimMarijke
                        cd :OffenderFreek
                        );
        cd :happensAt         "2010-01-02T20:00:00Z"^^xsd:dateTime  ;
        cd :locatedAt           cd :DomesticViolenceEvent1Loc  ;
        cd :nearbyEvent    (
               cd :RobberyEvent1
               cd :LostManEvent1
                cd :PublicConcert1
               )  ;
        cd :hasEmergencyLevel  cd:UrgentLevel .

cd :domesticViolenceEvent1Loc
        cd :isSpotOf    cd :domesticViolenceEvent1  ;
        cd :isNearby    (
               cd :robberyEvent1Loc
               cd :lostManEvent1Loc
                   cd :publicConcert1Loc
               )  ;
        cd :locName     [
               cd :country  "The Netherlands"^^xsd:string  ;
               cd :city       "Delft"^^xsd:string  ;
               cd :street     "Hulzenberg 25"^^xsd:string
               ].
```

Figure 9.2: Contextual Information Representation

- A domestic violence event *targeted by* police officer “Jan” happens at “22:00:00, 2010-01-01”. This urgent event (*emergency level*) involves the offender and a victim (*involvedObject*). This targeted event is nearby three other events (*nearbyEvent*): a robbery event, a lost old man event as well as a public concert event.
- The spot of a domestic violence event is at “Hulzenberg 25” (*street*), “Delft” (*city*), “the Netherlands” (*country*). This spot *is nearby* where three other events have happened.

9.4.2 Rule Sets Definition

In Chapter 8, a set of initial rules denoted as Rul_c and an extended rule set denoted as Rul_{c+p} were engineered (see Section 8.5.2) based on the two use cases. In order to adapt to the case of the domestic violence scenario, two extended rule sets denoted by $Rul_{c+p+v'}$ and Rul_{c+p+v} were developed by adding additional rules for dataset D_v. Specifically, the rule set $Rul_{c+p+v'}$ with *scenario-based* rules was engineered without requiring relevance judgements explicitly. Whereas, the rule set Rul_{c+p+v} was developed by modifying those *scenario-based* rules in $Rul_{c+p+v'}$ according to the relevance judgements provided by end-users (so called *rating-based* rules).

- $Rul_{c+p+v'}$: containing the rules from Rul_{c+p} in addition to *10 scenario-based* rules for adapting to the dataset D_v.
- Rul_{c+p+v}: consisting of the rules from Rul_{c+p} and *15 rating-based* rules for adapting to the dataset D_v.

Take one *scenario-based* rule in the rule set $Rul_{c+p+v'}$ for example. This rule ($R1$) listed below was developed to deal with the information concerning *criminal behaviors*. Since such information describes the ongoing crime behaviors of targeted objects, it is necessary to add certain time filter conditions in the body of rules for assess the relevance of such information, which is the main difference compared to those rules for dealing with *criminal records*.

- $R1$. **infoType**($?msg$, CriminalBehavior) & **describedObject** ($?msg$, $?person$) &
  isInvolvedIn ($?person$, $?event$) & **isTargetedBy**($?event$, $?user$) &
  engagedIn ($?user$, $?task$) & **targetedObject**($?task$,$?person$) &
  inPhaseOf($?user$, InitialInvestigation) & **startTime**($?task$,$?startTime$) &
  reportTime ($?msg$, $?reportTime$) & [$?reportTime \geq ?startTime$ - 30m]
  $\Longrightarrow$
  updateRating $(+5.0)$

According to the relevance judgements provided by police officers in the study (see Section 9.3), the relevance of information items which describe ongoing crime behaviors is higher for police officers who are in the phase of *departure* than who are in the phase of *initial investigation*. To cater to this information need, we engineered the two *rating-based* rules Rul_{c+p+v} by refining $R1$. One rule was built by just changing the rating value specified in the head of R1 to "+2.0". While another one was developed by modifying the condition that specifies the phase, i.e. changing the class name from "InitialInvestigation" to "Departure". This simple example shows how we engineered the *scenario-based* rules and modified them according to the relevance judgements.

9.5 Evaluation

Following the same evaluation method presented in Chapter 8 (see Section 8.4), CRAS was evaluated in strict and lenient modes with respect to the top-k ($k \in \{5, 10\}$) information items retrieved in terms of Precision ($P_\alpha@k$, ($\alpha \in \{$*strict, lenient*$\}$) and Recall ($R_\alpha@k$) and also F-Measure ($F_\alpha@k$).

9.5.1 Configurations

By the reuse of the two use cases and the two rule sets constructed in Chapter 8 (see Section 8.3), the behavior of CRAS was evaluated for four rule sets on three datasets with respect to the following configurations.

1. In order to assess the generality of CRAS, the rule sets Rul_c and Rul_{c+p} were applied to a forward use case D_v.

2. With the goal of investigating the adaptability of CRAS to a different use case, two extended rule sets $Rul_{c+p+v'}$ and Rul_{c+p+v} were applied to the dataset D_v. In particular, by applying $Rul_{c+p+v'}$ on D_v, it can demonstrate the behavior of CRAS to a forward case by adding additional rules without relying on the collection of relevance judgements.

3. To understand the influence of additional rules on the behavior of CRAS to backward cases, the rule sets $Rul_{c+p+v'}$ and Rul_{c+p+v} were applied on the two backward use cases D_c and D_p, respectively.

9.5.2 Results

The overall results of our rule-based system with respect to the above configurations are presented in Table 9.2. For each configuration, we averaged the values of evaluation measures (i.e. precision and recall and also F-Measure) for the four phases per scenario as shown in Table 9.3. By evaluating CRAS on the basis of four rule sets and three datasets, the three questions posted in Section 9.1 can be addressed.

First, the generic configurability of CRAS was further investigated by applying the current rule sets to a forward use case. Further, the results are compared to that of the rule set extended to cover this use case.

1. As Figure 9.3 shows, in strict mode, both of the rule set Rul_c and the extended rule set Rul_{c+p} provide the F-Measures ranging between 0.5 ($F@10$) and 0.55 ($F@5$) on the dataset D_v. Compared to the F-Measures between 0.65 ($F@10$) and 0.68 ($F@5$) given by the rule set Rul_{c+p+v} that was extended to cover the use case D_v, the performance provided by the rule sets Rul_c and Rul_{c+p} is reasonable.

2. As Figure 9.4 shows, in lenient mode, the rule set Rul_c achieves the F-Measures between 0.50 ($F@5$) and 0.65 ($F@10$) on the dataset D_v. While the Rul_{c+p} yields the F-Measures between 0.50 ($F@5$) and 0.69 ($F@10$) on D_v. Compared these results to the F-Measures between 0.50 ($F@5$) and 0.77 ($F@10$) yielded in the case of applying the rule set Rul_{c+p+v} to D_v, the performance of the rule sets Rul_c and Rul_{c+p} is also acceptable.

From the above results, we can arrive at the conclusion that:

- The current rules can provide a reasonable performance for forward cases and thus show the generic configurability of CRAS.

Second, to answer the question that is it possible to adapt CRAS to forward use cases without relying on the relevance judgments, CRAS was evaluated by applying the rule set extended with *scenario-based* rules to that scenario. By comparing the results to that of the rule set extended with *rating-based* rules, it can be seen that:

- In strict mode (see Figure 9.5), the rule set $Rul_{c+p+v'}$ gives the F-Measure between 0.55 ($F@5$) and 0.62 ($F@10$) on the dataset D_v. This result is comparable

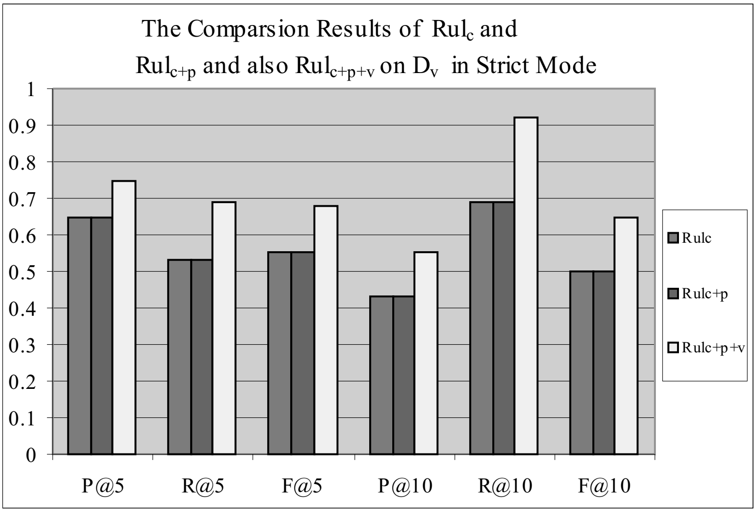

Figure 9.3: The Results of Rule Sets on a Forward Use Case in Strict Mode

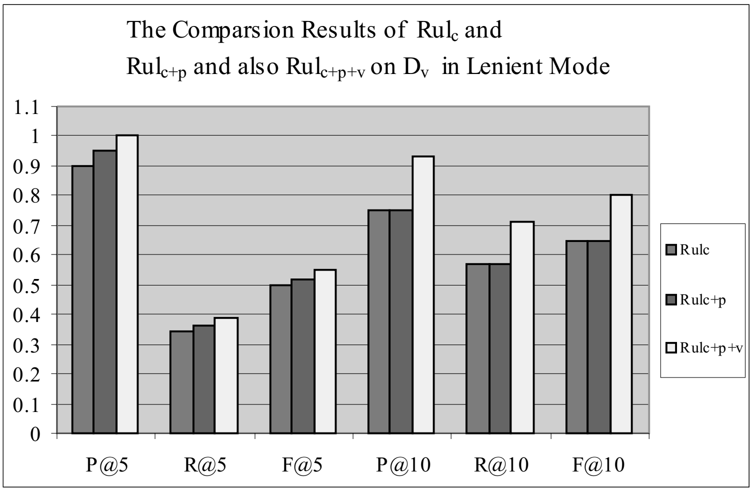

Figure 9.4: The Results of Rule Sets on a Forward Use Case in Lenient Mode

$Rul_{c+p+v'}$													
Eval. Mode		**Strict**						**Lenient**					
	Phase	P@5	R@5	F@5	P@10	R@10	F@10	P@5	R@5	F@5	P@10	R@10	F@10
D_v	1.	1.00	0.45	0.63	0.90	0.82	0.86	1.00	0.31	0.43	1.00	0.56	0.71
	2.	0.80	0.57	0.67	0.50	0.71	0.59	1.00	0.31	0.48	1.00	0.63	0.77
	3.	0.20	0.33	0.25	0.30	1.00	0.46	1.00	0.41	0.59	0.80	0.67	0.73
	4.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.31	0.47	0.90	0.56	0.69
D_p	1.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.50	0.67	0.80	0.80	0.80
	2.	0.40	1.00	0.57	0.20	1.00	0.33	0.60	0.38	0.46	0.60	0.75	0.67
	3.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.44	0.57	0.70	0.78	0.74
	4.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.44	0.57	0.80	0.89	0.84
D_c	1.	1.00	0.83	0.91	0.60	1.00	0.75	1.00	0.56	0.71	0.80	0.89	0.84
	2.	0.80	1.00	0.89	0.40	1.00	0.57	1.00	0.56	0.71	0.80	0.89	0.84
	3.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.50	0.67	0.90	0.90	0.90
	4.	0.40	1.00	0.57	0.20	1.00	0.33	1.00	0.56	0.71	0.70	0.78	0.74
Rul_{c+p+v}													
D_v	1.	1.00	0.45	0.63	0.90	0.82	0.86	1.00	0.28	0.43	1.00	0.56	0.71
	2.	0.80	0.57	0.67	0.60	0.86	0.71	1.00	0.31	0.48	1.00	0.63	0.77
	3.	0.60	1.00	0.75	0.30	1.00	0.46	1.00	0.42	0.59	1.00	0.83	0.91
	4.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.31	0.48	0.90	0.56	0.70
D_p	1.	0.60	0.75	0.67	0.40	1.00	0.57	1.00	0.50	0.67	0.80	0.80	0.80
	2.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.50	0.62	0.60	0.75	0.67
	3.	0.40	1.00	0.57	0.20	1.00	0.33	1.00	0.56	0.71	0.70	0.78	0.74
	4.	0.40	1.00	0.57	0.20	1.00	0.33	0.80	0.44	0.57	0.80	0.89	0.84
D_c	1.	0.80	0.67	0.73	0.60	1.00	0.75	1.00	0.56	0.71	0.80	0.89	0.84
	2.	0.80	1.00	0.89	0.40	1.00	0.57	1.00	0.56	0.71	0.80	0.89	0.84
	3.	0.80	1.00	0.89	0.40	1.00	0.57	1.00	0.50	0.67	0.90	0.90	0.90
	4.	0.40	1.00	0.57	0.20	1.00	0.33	1.00	0.56	0.71	0.70	0.78	0.74
Rul_{c+p}													
D_v	1.	1.00	0.45	0.63	0.70	0.64	0.67	1.00	0.28	0.43	0.90	0.50	0.64
	2.	0.80	0.57	0.67	0.50	0.71	0.59	1.00	0.31	0.48	0.90	0.56	0.69
	3.	0.20	0.33	0.25	0.20	0.67	0.31	1.00	0.42	0.59	0.80	0.67	0.73
	4.	0.60	0.75	0.67	0.30	0.75	0.43	0.80	0.31	0.48	0.90	0.56	0.69
Rul_c													
D_v	1.	1.00	0.45	0.63	0.70	0.64	0.67	1.00	0.27	0.44	0.80	0.44	0.57
	2.	0.80	0.57	0.67	0.50	0.71	0.59	1.00	0.31	0.48	0.90	0.56	0.69
	3.	0.20	0.33	0.25	0.20	0.67	0.31	1.00	0.42	0.59	0.70	0.58	0.64
	4.	0.60	0.75	0.67	0.30	0.75	0.43	1.00	0.31	0.48	0.90	0.56	0.69

Table 9.2: The Evaluation Results in Given Phases Per Scenario

to that of the F-Measure between 0.68 (F@5) and 0.65 (F@10) given by the rule set Rul_{c+p+v}.

- In lenient mode (see Figure 9.6), the rule set $Rul_{c+p+v'}$ provides the F-Measure between 0.50 (F@5) and 0.73 (F@10) on the dataset D_v. This result is very close to that of the F-Measure between 0.50 (F@5) and 0.77 (F@10) given by the rule set Rul_{c+p+v}.

Through the above comparison, we thus can conclude that:

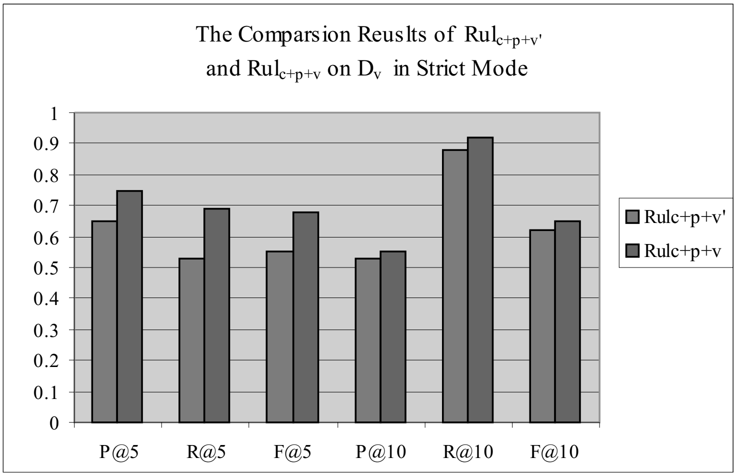

Figure 9.5: The Results of Extended Rule Sets on a Forward Use Case in Strict Mode

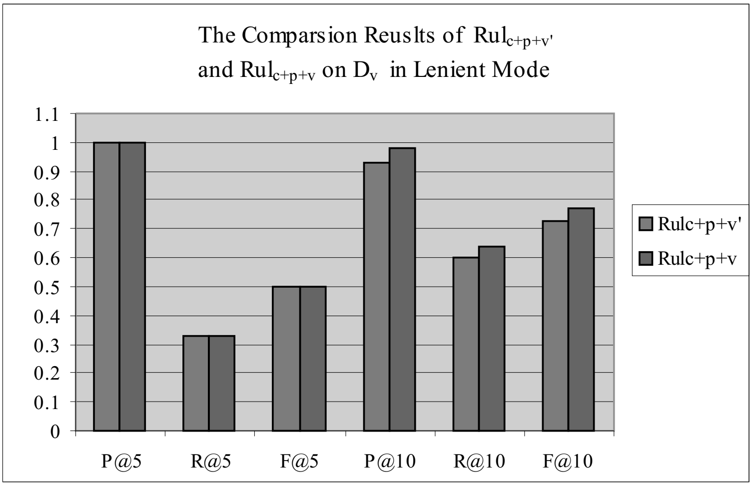

Figure 9.6: The Results of Extended Rule Sets on a Forward Use Case in Lenient Mode

Eval. Mode	Strict						Lenient					
	P@5	R@5	F@5	P@10	R@10	F@10	P@5	R@5	F@5	P@10	R@10	F@10
$Rul_{c+p+v'}$												
D_v	0.65	0.53	0.55	0.53	0.88	0.62	1.00	0.33	0.50	0.93	0.60	0.73
D_p	0.45	0.94	0.60	0.25	1.00	0.40	0.80	0.44	0.57	0.72	0.80	0.76
D_c	0.70	0.90	0.76	0.40	1.00	0.56	1.00	0.54	0.70	0.80	0.86	0.83
Rul_{c+p+v}												
D_v	0.75	0.69	0.68	0.55	0.92	0.65	1.00	0.33	0.50	0.98	0.64	0.77
D_p	0.45	0.94	0.60	0.25	1.00	0.39	0.90	0.50	0.64	0.72	0.80	0.76
D_c	0.70	0.92	0.77	0.40	1.00	0.56	1.00	0.54	0.70	0.80	0.86	0.83
Rul_{c+p}												
D_v	0.65	0.53	0.55	0.43	0.69	0.50	1.00	0.33	0.50	0.88	0.57	0.69
D_p	0.45	0.94	0.60	0.25	1.00	0.39	0.90	0.50	0.64	0.80	0.89	0.84
Rul_c												
D_v	0.65	0.53	0.55	0.43	0.69	0.50	1.00	0.33	0.50	0.83	0.54	0.65
D_c	0.70	0.90	0.76	0.40	1.00	0.56	0.95	0.51	0.67	0.83	0.90	0.86

Table 9.3: The Average of the Evaluation Results

- CRAS can be adapted to forward use cases without relying on an already known set of relevance judgements. In another word, the rule set extended to adapt the behavior of CRAS to a forward use case is able to cover this case without taking into account the relevance judgements.

Third, with the aim of addressing the question how the additional rules that adapt CRAS to a forward use case influence the behavior of CRAS on backward use cases, the two sets of rules extended for dealing with a forward use case were applied not only to that case but also to backward cases.

1. The results of CRAS in the case of applying the rule set $Rul_{c+p+v'}$ to dataset D_v is shown in Table 9.3. To compare CRAS to the state of the art of context-aware applications, we considered a contextual information retrieval system (named ICARUS) (Lu et al., 2011) in spite of the fact that it was designed for a different domain. Because ICARUS (Information in Context: Automated Retrieval User Service) was evaluated in a similar evaluation methodology as CRAS. We compared the top-10 ranked results of CRAS to that of ICARUS. The results show that:

   (1) CRAS can achieve higher recall values, i.e. between 0.64 (lenient) and 0.92 (strict) compared to 0.4 and 0.72 yielded by ICARUS.

   (2) With respect to precision, the precision of CRAS between 0.55 (strict) and 0.98 (lenient) outperforms the precision of ICARUS between 0.4 and 0.61.

2. By applying the two extended rule sets $Rul_{c+p+v'}$ and Rul_{c+p+v} to the two backward use cases D_c and D_p, the results show that:

   (1) Compared to the performance of the rule set Rul_c on the scenario D_c, both $Rul_{c+p+v'}$ and Rul_{c+p+v} give consistent results in strict mode, while there is only a slight influence on the results measured in lenient mode. In fact, $F@5$ is increased by 0.03 while $F@10$ is decreased by 0.03 (see Figure 9.7).

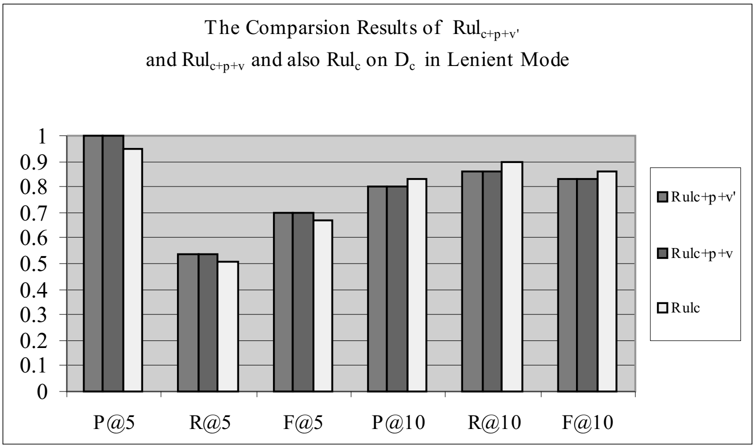

Figure 9.7: The Results of Rule Sets on an Initial Use Case in Lenient Mode

(2) Compared to the behavior of CRAS provided by the rule set Rul_{c+p} on scenario D_p, the results demonstrate that both of $Rul_{c+p+v'}$ and Rul_{c+p+v} give all the same value in strict mode, whereas they only slightly change some values in lenient model. It can be seen from Figure 9.8 that the rule set $Rul_{c+p+v'}$ degrades $F@5$ by 0.07 and $F@10$ by 0.08, while Rul_{c+p+v} decreases $F@10$ from 0.84 to 0.76.

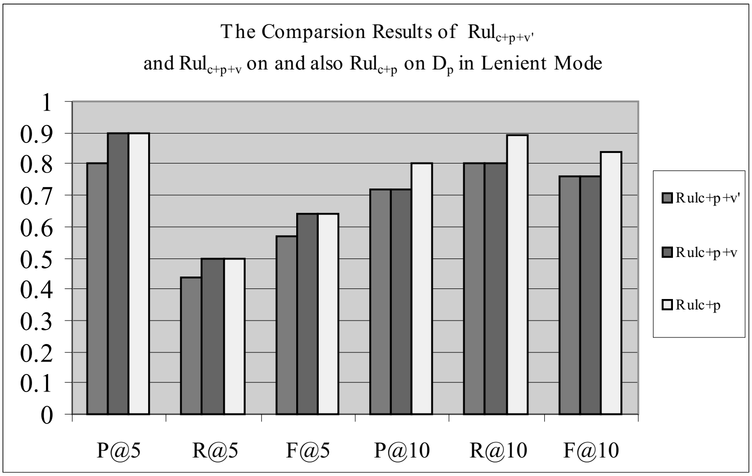

Figure 9.8: The Results of Rule Sets on a Backward Use Case in Lenient Mode

According to the above comparison analysis, we can conclude that:

- CRAS can be adapted to a different scenario easily by only adding additional rules. More importantly, those additional rules gradually improve CRAS on a forward use case while not significantly degrading the performance on backward cases.

9.6 Conclusion

In order to show the feasibility of our architecture (CIDA), a rule-based system (CRAS) was developed for assessing the relevance of information items for police officers by taking into account their contextual situations. To to be applied in practice, CRAS was designed to meet the following important requirements: (1) CRAS should effectively select relevant information given end-users' contextual situations; (2) CRAS should have generic configurability in the sense that it is able to cover different scenarios; and (3) CRAS should be easily adapted to different scenarios with a modest effort. To demonstrate how (and if) CRAS could meet the above requirements, we evaluated the effectiveness, generic configurability and in particular the adaptability of CRAS in Chapter 8 and 9.

Following our evaluation method, CRAS was evaluated in the context of given scenarios in Chapter 8 in order to address the three questions we posted. The results demonstrated that the precision and recall levels achieved by CRAS are high. With the goal of further evaluating CRAS on different use cases, in this chapter we constructed a new use case and focused on assessing the adaptability of CRAS to this case. In particular, we proposed two sub-questions in order to further investigate how CRAS can be adapted to different cases.

Firstly, we collected a new scenario on the basis of an interview with domain experts and constructed a relatively realistic use case consisting of a certain number of information items. Then, we performed a study in cooperation with police officers who were asked to judge the relevance of those constructed information items in specific phases of that scenario. Further, we engineered the two extended sets of rules given that use case. Specifically, one set was engineered by adding *scenario-based* rules but without taking into account relevance judgements; whereas another set was built by adding *rating-based* rules that were modified according to relevance judgements based on those *scenario-based* rules.

By the reuse of the scenarios presented in Chapter 8, CRAS was evaluated for four rule sets on three use cases with regard to different configurations. For each of these 12 configurations ($4 \times 3 = 12$), the retrieved information items (i.e. top-5 and top-10) were evaluated with respect to the gold standard in terms of Precision/Recall and F-Measure in two evaluation modes: (1) strict and (2) lenient. The results provide answers to all questions we proposed and thus demonstrate that:

- CRAS can be configured such that it is able to select adequately relevant information for end-uses given their context.
- CRAS has generic configurability in the sense that it provides reasonable performance by applying current rule sets on forward cases.
- CRAS is adaptable to forward use cases easily by only adding additional rules.
- Those additional rules for adapting CRAS to a forward case can be engineered without relying on an already known set of relevance judgements.
- Those additional rules gradually improve the behavior of CRAS on a forward use case while not significantly degrading the performance on backward use cases.

As corroborated by the above competitive results, we conclude that CRAS meets the requirements and CIDA is feasible to be applied in practice.

Part VI

Conclusion and Future Work

Chapter 10

Conclusion and Future Work

The typical mobile users of today such as police officers acting in an evolving situation require information tailored to their current context in order to make effective decisions. With the goal of addressing this requirement, an increasing number of researchers have focused on seeking solutions for providing context-aware services. The use of context to provide task-relevant information and/or services to mobile users has posed many challenges within the field of context-awareness. Our research is motivated by the challenge to deliver contextualized information that can support mobile users in performing their task. In the context of MOSAIC project[1] which is a joint effort between DECIS lab and vtsPN, we consider police officers involved in mobile police work as our end-users. The specific goal of our research is to provide task-relevant information to police officers by taking into account the characteristics of their working environment and their task at hand.

The main objective of this thesis is to develop a solution for contextualized information delivery. To achieve this goal we investigated the following research questions:

- Q1. What are specific information needs of police officers in the context of dealing with small-scale events?
- Q2. What are the requirements for a generic architecture for the delivery of contextualized information to mobile users?
- Q3. How can an architecture be designed to support delivery of contextualized information to mobile users?
- Q4. How can we model contextual situations of mobile users engaged in tasks aimed at certain events?
- Q5. How can a system for contextualized relevance assessment be implemented to show the feasibility of the architecture?
- Q6. How can we evaluate the system developed for the domain of mobile police work?

In Chapter 3 we investigated the first research question by conducting a questionnaire-based study of the work of police officers. On the basis of a number of realistic scenarios, we

[1] http://www.icis.decis.nl/index.php/lang-nl/projects/id-and-valorization/187-mosaic

identified and represented the information needs of police officers in the context of dealing with routine incidents. In Chapter 4 we stated the requirements derived from the study and thus provided answers to the second research question. Following these requirements, we discussed our design considerations and presented an architecture (CIDA) for delivering contextualized information to mobile users in order to address the third research question. In Chapter 5 we illustrated how dynamic messages and static background information were formalized in an information item model using RDF. In particular, we tackled the fourth research question by establishing an ontology-based context model consisting of a generic ontology and a domain ontology specific for mobile police work. We defined a rule language (MRRL) for specifying how to update the relevance of information items in a given context in Chapter 6, and implemented a rule engine (RARE) for executing those rules defined as MRRL in Chapter 7. The rule engine supports us to develop a rule-based system (CRAS) adapted to the domain of mobile police work for assessing the relevance of information items. Thus, we demonstrated the applicability of CIDA and addressed the fifth research question. In the final part of the thesis we provided answers to the sixth research question through two evaluation studies. In Chapter 8 we posed three questions to investigate the effectiveness and generic configurability and also adaptability of CRAS. Also, we presented the construction of datesets and rule sets. Following our evaluation method, CRAS was evaluated based on two use cases. In Chapter 9, in order to further investigate the generic configurability and adaptability of CRAS to different scenarios, we constructed a new use case in cooperation with domain experts and engineered two sets of rules adapted to this case by different methods. Then, we evaluated CRAS for four rule sets on three use cases with respect to different configurations and presented overall results.

In this chapter we discuss our conclusions and contributions related to the six research questions that we investigated (in Section 10.1) and present the direction for future work (in Section 10.2).

10.1 Contributions

In this section we detail our main conclusions and describe our scientific contributions. We organize our discussion around the six research questions we addressed.

10.1.1 Information Needs

Given that the delivery of contextualized information to mobile users is a central theme in our research work, a prerequisite is to know the specific information needs of end-users (police officers in our case) involved in a certain contextual situation. There are at least two challenges for identifying the information needs of police officers. One is that police officers engaged in handling unforeseen events are often involved in very dynamic situations; another is that actual work activities of police officers relying significantly on experience and informal rules are hard to describe in precise terms.

In order to receive a first hand sense of how (and if) the information needs of police officers change in an evolving situation while carrying out their tasks, we conducted a questionnaire-based study in Chapter 3 which revealed the typical information needs of police officers in the context of given scenarios. From our observations in this study, we concluded that:

- The information needs of police officers are highly specific for the given phases in which they are involved. The notion of "*phase*" as we defined is understood in a broad sense, as a period in which responders are engaged in some logical part of a task following the incident response procedure. Specifically, we defined four phases in our scenarios. An example of a phase that a police officer could be in is "initial investigation", which implies that a police officer is involved in activities for becoming familiar with the scene of the event, such as inspecting a location or some object, interviewing a witness, etc.

- When a police officer is in a particular phase, certain categories of information are more relevant than others.

- We identified which categories of information police officers require in which phase.

Our contribution is the identification of the specific information needs of police officers in a given context.

10.1.2 Requirements

With the goal of designing a generic architecture for contextualized information delivery, we derived the requirements for the architecture design from the information needs study (see Section 4.1).

According to our observations from the study, an architecture supporting delivery of contextualized information should fulfill the following requirements:

- The finding that the information needs are highly specific for the phase end-users are in, yields a crucial requirement: the architecture should consist of a component that can represent dynamic aspects of a user's situation, such as the task at hand, the events that happen and current phase. Note that these go beyond the classical dimensions of context, i.e. time and location.

- The finding that certain categories of information are more relevant than others within a specific phase generates a requirement: the architecture should include a component that is able to integrate and exploit different categories of information. That information could come from either dynamic message sources, such as sensors, or static background information sources, like criminal records.

- The results that identify which categories of information end-users require in which phase leads to the following requirement: the architecture should support the development of systems which can determine the relevance of information given a user's context.

Our contribution is a set of requirements for the design of a generic architecture supporting the delivery of relevant information in a contextualized setting.

10.1.3 Architecture

Many proposed context-aware architectures and frameworks that are capable of dealing with special types of context are well-suited for specific application domains, such as for a hospital environment. To the best of our knowledge, only few studies offer flexible and extensible architectures for supporting context-aware applications.

In order to meet the requirements indicated in 10.1.2, we have materialized our design considerations in terms of information models and the workflow of the relevance assessment.

- We designed an ontology-based context model which represents the current contextual situation of mobile users who are engaged in the task of handling a certain event.
- We formalized information from dynamic and also static sources in terms of an RDF data model and schema.
- We designed the components of the architecture and defined how they interact to fulfill the core functionality of the relevance assessment.

In Chapter 4 we designed CIDA and defined the functionality of single components. The main components of CIDA consist of (1) a situational data (i.e. context data) repository; (2) an information item repository; (3) a rule store; and (4) a rule engine. This architecture supports the development of rule-based systems which can provide information to a specific user in a given context by computing the relevance of information depending on the user's contextual situation.

We contribute the design of a generic architecture for contextualized information delivery for mobile users.

10.1.4 Context Model

Establishing a model for dealing with changing context of mobile users is a critical aspect of providing adaptive context-aware services. Following the definition provided by (Dey and Abowd, 1999), context is any information that can be used to characterize the situation of an entity. Many existing context modelling approaches take into account spatial and temporal dimensions, but a few of them incorporate both the type of task that users are engaged in and a certain event that users are dealing with. For our purpose, the current situation of a user consists of a user profile, task at hand, target events and spatio-temporal context. Due to the high and formal expressiveness of ontologies and the possibilities for applying ontology reasoning techniques, more and more context-aware frameworks use ontologies as underlying context models (Baldauf et al., 2007).

Since the evaluation of different approaches for modelling of context information has showed that ontologies are the most expressive models (Strang and Linnhoff-Popien, 2004), we established an ontology-based context model, in order to characterize the contextual situations of mobile users and in particular represent the characteristics of working environment of police officers. Our context model presented in Chapter 5 consists of a generic ontology and a domain-specific ontology:

- **A generic ontology**. This is based on the four primary context types, viz. identity, location, activity and time, defined by (Dey et al., 2001), and an upper ontology for situation awareness provided by (Matheus et al., 2005), which contains the *EventNotice* class for describing events in a real-world situation and indicating changes in the situation. The generic ontology in our context model thus describes four dimensions of a user's context, i.e. time, location, event, and task. Moreover, our context model reveals the relationships between these dimensions at a semantic level. For instance, the *isTargetedBy* predicate, which has as domain Event and as range User, reveals the relation between an event and a user representing which event is targeted by which user.

- **A domain-specific ontology**. Our context model was designed to be extended to support domain-specific needs. The domain-specific ontology creates a subclass of the User class to define the role of police officers, and the properties of the Event class to describe the objects involved in an event as well as an emergency level of an event. In addition, the User class was extended to have the property *inPhaseOf*, which specifies a specific period end-users are involved in, described by the four subclasses of the Phase class.

Our contribution is an ontology-based context model which incorporates task and event dimensions of context beyond the usual spatio-temporal context dimension. Moreover, our context model was defined to be extensible for adapting to the domain of mobile police work and thus represent the contextual situations of police officers.

10.1.5 Rule-based System

With the goal of demonstrating the feasibility of CIDA, we developed the Contextualized Relevance Assessment System (CRAS) which can assess the relevance of information items according to the contextual situations of police officers. The adaptability of CRAS relies on a rule engine which was designed to execute declarative rating rules. The rule language and engine are explained as follows:

- **Message Rating Rule Language (MRRL)**. MRRL was inspired by SWRL[2] (Semantic Web Rule Language) and was adapted for the purpose of generating a cumulative rating of an information item for a given user in a given context (See Chapter 6). The body of the rules specifies the conditions that need to be fulfilled and the head specifies how to update the relevance of information items. MRRL contains no constraint that is only specific for our application domain.

- **Relevance Rating Rule Engine (RARE)**. RARE was implemented for executing MRRL rules in order to compute the relevance of information items depending on the specific needs of users in a particular context (See Chapter 7). RARE supports the reconfiguration of the behavior of CRAS by the specification of different sets of rules without the need for reprogramming.

[2]http://www.w3.org/Submission/SWRL/

Our contribution is a rule-based system for assessing the relevance of information items depending on specific needs of police officers in a given context in order to support their task at hand.

10.1.6 Evaluation

Quantitative evaluation of a rule-based system is a non-trivial task. Compared to the current technology for evaluating context-aware applications in emergency situations, we more focus on evaluating how well our system could meet end-users' requirements in a quantitative way. In order to assess CRAS in terms of the effectiveness and the generic configurability and in particular the adaptability, we constructed the datasets as well as rule sets and presented the questions to be investigated in two evaluation studies. Then, following our evaluation method, CRAS was evaluated with regard to different configurations. For each configuration, the results were measured in terms of precision and recall with respect to a gold standard in strict as well as lenient modes (See Chapter 8 and 9).

Data Construction. As for the dataset definition, each dataset consists of a number of information items and context information corresponding to a scenario. All datasets are representative given that they were constructed in cooperation with experienced police officers based on realistic scenarios. For engineering the rule sets, a set of initial rules was developed corresponding to a scenario as a starting point. In order to deal with a forward use case (a test set), which describes a new type of a scenario, the rule set was incrementally extended in such a way that adding additional rules on top of current rules without changing the current ones. On the basis of three use cases, we developed a set of an initial rules and three sets of rules that were incrementally extended. More specifically, for covering a new use case, in Chapter 9 one set of rules was extended by adding additional rules without requiring the collection of relevance judgments (i.e. adding *scenario-based* rules), while another set was extended with *rating-based* rules that were modified based on those *scenario-based* rules according to the provided relevance judgments.

Evaluation Method. Our evaluation method was defined to assess CRAS on the basis of datasets and rule sets.

- The effectiveness of CRAS was evaluated by applying a set of initial rules to the corresponding dataset.
- The generic configurability of CRAS was assessed by applying the current rule sets to forward use cases (test sets).
- To investigate the adaptability of CRAS, the rule sets that were incrementally extended for covering forward use cases were applied to those cases. Furthermore, the influence of additional rules for adapting CRAS to forward use cases was assessed on backward cases (training sets).

CRAS was evaluated for four rule sets on three use cases with respect to different configurations. For each of these 12 (4×3) configurations, the results were evaluated with respect to the top-k (top-5 and top-10) information items retrieved in terms of Precision/Recall and

F-Measure in two evaluation modes: (1) strict and (2) lenient. In strict mode, only items rated as *highly relevant* according to the gold standard are considered as correct. While in lenient mode all *relevant* items are regarded as correct.

Results. The two evaluation studies show that the precision and recall levels of CRAS are competitive compared to a phase-specific baseline and an event-specific baseline we defined. We concluded that:

- CRAS can be configured such that it is precise enough to select adequate information for end-users given their context.
- CRAS has generic configurability in the sense that it provides reasonable performance by applying current rule sets on forward cases.
- CRAS can be adapted to forward use cases easily by only adding additional rules.
- The extended rule set for adapting CRAS to a forward use case is able to cover this case without relying on an already known set of relevance judgements.
- Those additional rules gradually improve the behavior of CRAS on a forward use case while not significantly degrading the performance on backward use cases.

Our contribution at this point, besides giving an insight in the behavior of CRAS based on realistic scenarios, is a quantitative evaluation method that can be used to evaluate rule-based systems for contextualized relevance assessment. We constructed three datasets in cooperation with domain experts and defined the gold standard relying on the collected relevance judgements. Following our evaluation method, we evaluated the effectiveness and generic configurability and in particular the adaptability of CRAS with respect to different configurations. We demonstrated the feasibility of CIDA as corroborated by the competitive results of CRAS and the positive answers for the properties of CRAS.

10.2 Future Work

With the ultimate goal of contextualized information delivery for mobile police officers, in this thesis we tackled several challenges in terms of information need study, architecture design, information model establishment, system development and evaluation. However, even if we addressed several issues in the context of context-awareness service, we envision that important research still has to be done in order to address the limitations in this thesis. We discuss possible future work in this section.

CIDA Extension. The development of our rule-based system in the context of CIDA relies on several assumptions: (1) all information processed by CRAS can be formalized according to the RDF data model on the fly. (2) Fine-grained context information can be derived from sensor and other information and also can be made explicit. (3) Relevant messages can be delivered to end-users in a desirable manner. In order to apply CRAS in practice, we plan to expand CIDA by developing and implementing the following components:

1. **Information extraction component**. It extracts relevant facts from real-time messages as well as background information, thus enables the automatic formalization of all information using RDF. There are at least two ways for obtaining formalized information. First, research in the area of information extraction is quite mature and there are various approaches available for us that can extract relevant information from free text (Hobbs and Riloff, 2010). Second, we expect that formalized information can be obtained from filled templates. For instance, in our case, some contextual information can be entered into the information system through forms while officers in the CCR are attending emergency calls.

2. **Inference component**. One limitation of our research is that we did not develop a component in CIDA that can infer the specific phase of a user is currently in, although we understand that having such a component is a very crucial requirement for applying CRAS in practice. In this sense, an important avenue for future work is the development of a component that can infer the current phase that police officers are actually in on the basis of sensors and other information sources. We noticed possible approaches that can help us to derive information about a user's activity or phase. In principle, inference engines such as CoBrA (Chen et al., 2003) can be used to infer higher level contexts from low level sensed contexts. For our specific case, at least in routine tasks where police officers follow the standard procedure, the police officers themselves can update their phase in the form of messages via a mobile device for instance. By using machine learning techniques, we plan to design algorithms that can find correlations between the features extracted from those messages and the specific phase users in.

3. **Message presentation component**. This component will be implemented to decide how many relevant messages should be delivered according to the display capability of a mobile device, when to deliver those messages depending on the user's attention and workload, and what is the desirable presentation style according to the user's preferences. In particular, we plan to define presentation strategies that can be adapted to availability of the user and message priority (Streefkerk, 2011).

Context Reasoning. An ontology-based context model is able to address critical issues including formal context representation and logical based context reasoning (Wang et al., 2004). Our context model has explored the high and formal expressiveness of ontologies. By the use of the reasoning power of ontologies, we plan to enhance our context model to deduce new knowledge based on the available context data, and to check and solve inconsistent context knowledge (Dejene et al., 2007; Gu et al., 2004). Specifically, we will focus on the temporal representation and reasoning relying on the OWL-Time ontology[3] in order to detect and infer critical situations from a series of temporal events.

Rule Language Rule Engine. Our rule language MRRL, supporting basic logical and mathematic operators, can express the specific relations between context dimensions. In order to deal with more types of context, the syntax of MRRL should be extended to support more expressions, for instance, negated conditions. We plan to expand RARE by devising

[3] http://www.w3.org/TR/owl-time/

a mechanism that facilitates debugging and validation of the rules. Also, we will develop a better algorithm to determine when rules are triggered and how to execute them. In addition, we intend to take into account the fact that RDF graphs might be distributed, mostly by reusing techniques for distributed SPARQL queries.

User Interface. A context-sensitive user interface (Jiang et al., 2004), which can understand a user's needs and act accordingly, plays an important role in improving the user's interaction experience. Our research will focus on the design of such a user interface that can highlight a point of interest and also attract the user's attention to certain context areas. By the use of *focus+context* visualization techniques (Luyten et al., 2006), we intend to design an interface for end-users that not only can provide the required overview over the emergency situation, but also can emphasize critical information such as life-saving information.

Application and Evaluation in Other Domains. CIDA was designed specifically for contextualized information delivery for mobile users, by taking into account the characteristics of dynamic working environments. However, we argue that CIDA also supports delivering relevant information in non-mobile situations. In addition to the police domain, CIDA can be extended to work environments of other emergency responders such as firefighters and medical responders. We are convinced that CIDA can be applied to different domains for two reasons:

1. CIDA consists of an ontology-based context model which can represent the user's contextual situations. The generic context ontology is reusable in non-mobile settings (e.g. in-door environment) , since it incorporates the primary context types such as user profile and the task at hand. Moreover, it can represent the changing situations of users who are engaged in dealing with certain events and thus it is specifically applicable in mobile environments. More importantly, the generic ontology is extensible to define the details of the context concepts and their properties for other application domains. For example, in order to specify certain periods firefighters are in, the User class can be extended to have a subclass of FireFighters. Also, a set of new subclasses can be added to the Phase class to describe how firefighers perform their task following standard procedures.

2. CIDA supports the development of rule-based systems that show behavior that is configurable by the specification of MRRL rules. These MRRL rules, specifying which type of information to deliver in which context, can be modified independently of the code executing them, thus providing a principled way to adapt systems to new domains. As explain in 10.1.5, MRRL contains no constraint that is only specific for our application domain. Therefore, it is likely to be effective for also other domains.

Our evaluation methodology was defined to quantitatively evaluate the properties and in particular the adaptability of rule-based systems for contextualized information delivery. Following our evaluation methodology, we can further investigate how well our research findings could contribute to other domains. In the near future, we intend to demonstrate the generality of CIDA in different domains. First, we will perform information need studies to investigate how can we extend our context model to meet those domain-specific requirements. Then, we will extend the current sets of rules in order to cover new situations. Lastly, we will focus on evaluating the behavior of the system developed relying on CIDA in terms of precision and recall on the basis of new use cases.

Appendix A

A Gold Standard

The Gold Standard in the Domesitc Violence Scenario

Relevance	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
Highly Relevant	cd: involvedChildrenMsg1 cd: offenderBehaviorMsg2 cd: southOftheSpotnotAccessibleMsg6 cd: medicalRecordOnPsycholsisMsg7 cd: previousDomesticViolenceCallsMsg12 cd: illegalWeaponsRecordMsg17 cd: KeithHasViolenceRecordMsg22 cd: FightingNoiseMsg3 cd: probationOrderRecordMsg25 cd: victimWasChokedMsg5 cd: carPlateOfKeithMsg13	cd: offenderBehaviorMsg2 cd: involvedChildrenMsg1 cd: illegalWeaponsRecordMsg17 cd: medicalRecordOnPsycholsisMsg7 cd: previousDomesticViolenceCallsMsg12 cd: ViolenceRecordMsg22 cd: investigatedForChildrenAbuseMsg28	cd: illegalWeaponsRecordMsg17 cd: brokenArmRecordMsg21 cd: investigatedForChildrenAbuseMsg28	cd: victimWasChokedMsg5 cd: ViolenceRecordMsg22 cd: illegalWeaponsRecordMsg17 cd: brokenArmRecordMsg21
Relevant	cd: involvedChildrenMsg1 cd: offenderBehaviorMsg2 cd: southOftheSpotnotAccessibleMsg6 cd: medicalRecordOnPsycholsisMsg7 cd: previousDomesticViolenceCallsMsg12 cd: illegalWeaponsRecordMsg17 cd: KeithHasViolenceRecordMsg22 cd: FightingNoiseMsg3 cd: probationOrderRecordMsg25 cd: victimWasChokedMsg5 cd: carPlateOfKeithMsg13 cd: offenderInfluenceByAlcohol11 cd: investigatedForChildrenAbuseMsg28 cd: neighboursComplainMsg8 cd: drugsDealingRecordMsg31 cd: additionalPhoneCallsMsg29	cd: offenderBehaviorMsg2 cd: involvedChildrenMsg1 cd: illegalWeaponsRecordMsg17 cd: medicalRecordOnPsycholsisMsg7 cd: previousDomesticViolenceCallsMsg12 cd: ViolenceRecordMsg22 cd: investigatedForChildrenAbuseMsg28 cd: victimWasChokedMsg5 cd: probationOrderRecordMsg25 cd: brokenArmRecordMsg21 cd: offenderInfluenceByAlcohol11 cd: FightingNoiseMsg3 cd: neighboursComplainMsg8 cd: drugsDealingRecordMsg31	cd: illegalWeaponsRecordMsg17 cd: brokenArmRecordMsg21 cd: investigatedForChildrenAbuseMsg28 cd: offenderBehaviorMsg2 cd: victimWasChokedMsg5 cd: medicalRecordOnPsycholsisMsg7 cd: KeithHasViolenceRecordMsg22 cd: FightingNoiseMsg3 cd: probationOrderRecordMsg25 cd: additionalPhoneCallsMsg29 cd: drugsDealingRecordMsg31	cd: victimWasChokedMsg5 cd: ViolenceRecordMsg22 cd: illegalWeaponsRecordMsg17 cd: brokenArmRecordMsg21 cd: hasASisterInDelftMsg16 cd: investigatedForChildrenAbuseMsg28 cd: previousDomesticViolenceCallsMsg12 cd: involvedChildrenMsg1 cd: superKlusBVatSpotMsg14 cd: offenderInfluenceByAlcohol11 cd: probationOrderRecordMsg25 cd: blackMailingMsg27
Irrelevant	cd: victimEductionMsg4 cd: robberyEventMsg9 cd: superKlusBVatSpotMsg14 cd: lostManEventMsg15 cd: hasASisterInDelftMsg16 cd:concertAtSpotMsg18 cd:suspectMotorbikeMsg20 cd: hasADaughterMsg19 cd: brokenArmRecordMsg21 cd: unoccupiedAppartmentMsg23 cd: burglaryRecordMsg24 cd: debtRecordMsg26 cd: blackMailingMsg27 cd: sportsSchoolMsg30 cd: brotherAdressMsg32 cd: lostManEventClosedMsg33 cd: susptectMotorbikeMsg10	cd: victimEductionMsg4 cd: southOftheSpotnotAccessibleMsg6 cd: robberyEventMsg9 cd: susptectMotorbikeMsg10 cd: carPlateOfKeithMsg13 cd: superKlusBVatSpotMsg14 cd: lostManEventMsg15 cd: hasASisterInDelftMsg16 cd:concertAtSpotMsg18 cd: hasADaughterMsg19 cd:suspectMotorbikeMsg20 cd: unoccupiedAppartmentMsg23 cd: burglaryRecordMsg24 cd: debtRecordMsg26 cd: blackMailingMsg27 cd: additionalPhoneCallsMsg29 cd: sportsSchoolMsg30 cd: brotherAdressMsg32 cd: lostManEventClosedMsg33	cd: superKlusBVatSpotMsg14 cd: involvedChildrenMsg1 cd: lostManEventMsg15 cd: victimEductionMsg4 cd: southOftheSpotnotAccessibleMsg6 cd: neighboursComplainMsg8 cd: robberyEventMsg9 cd: susptectMotorbikeMsg10 cd: offenderInfluenceByAlcohol11 cd: previousDomesticViolenceCallsMsg12 cd: carPlateOfKeithMsg13 cd: hasASisterInDelftMsg16 cd:concertAtSpotMsg18 cd: hasADaughterMsg19 cd:suspectMotorbikeMsg20 cd: unoccupiedAppartmentMsg23 cd: burglaryRecordMsg24 cd: debtRecordMsg26 cd: blackMailingMsg27 cd: sportsSchoolMsg30 cd: brotherAdressMsg32 cd: lostManEventClosedMsg33	cd: superKlusBVatSpotMsg14 cd: lostManEventMsg15 cd: victimEductionMsg4 cd: southOftheSpotnotAccessibleMsg6 cd: neighboursComplainMsg8 cd: robberyEventMsg9 cd: susptectMotorbikeMsg10 cd: offenderInfluenceByAlcohol11 cd: previousDomesticViolenceCallsMsg12 cd: carPlateOfKeithMsg13 cd: hasASisterInDelftMsg16 cd:concertAtSpotMsg18 cd: hasADaughterMsg19 cd:suspectMotorbikeMsg20 cd: unoccupiedAppartmentMsg23 cd: burglaryRecordMsg24 cd: debtRecordMsg26 cd: blackMailingMsg27 cd: sportsSchoolMsg30 cd: brotherAdressMsg32 cd: lostManEventClosedMsg33

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Samenvatting

Op weg naar gecontextualiseerde informatievoorziening: een regelgebaseerde architectuur voor het domein van mobiel politiewerk

Voor het uitvoeren van activiteiten in een veranderende omgeving hebben de typische mobiele gebruikers van vandaag up-to-date informatie nodig voor het ondersteunen van hun activiteiten. Huidige web-service technologieën en de vooruitgang in mobiele apparatuur hebben de mogelijkheden vergroot om de juiste informatie te verstrekken aan de juiste persoon. Een groeiend aantal mobiele gebruikers vraagt om aanpasbare diensten toegesneden op hun specifieke behoeften in een specifieke situatie. Deze vraag vormde een grote uitdaging voor de ontwerpers en onderzoekers die contextbewuste systemen (context-aware systems) onderzoeken: *Hoe kunnen applicaties zich aanpassen aan de actuele omgeving van de mobiele gebruiker zonder te veel hun aandacht op te eisen?*

In tegenstelling tot gebruikers in de traditionele kantoorwerkomgevingen, wordt de context van mobiele gebruikers gekenmerkt door verandering. Deze context kan worden beschreven in termen van verschillende dimensies, inclusief de fysieke/externe context die kan worden verzameld door sensoren, zoals locatie, tijd, snelheid, enz., en de logische/interne context die gerelateerd is aan de activiteiten, het doel en eventueel zelfs de emotionele toestand van de gebruiker. Om aan de specifieke informatiebehoeften van mobiele gebruikers in een bepaalde context te voldoen, moeten contextbewuste applicaties niet alleen veranderingen van de context detecteren, maar ook bepalen welke informatie en diensten de huidige taken van de gebruiker kunnen ondersteunen. Een typisch voorbeeld daarvan zijn mobiele politieagenten die technische ondersteuning nodig hebben in de vorm van informatie systemen die zijn afgestemd op hun contextuele informatiebehoefte. Deze specifieke eisen vormen een grote uitdaging bij de ontwikkeling van contextbewuste systemen voor de ondersteuning van mobiel politiewerk vanwege de volgende redenen. (1) Een routine situatie van de politie kan op ieder moment evolueren tot een urgente situatie. (2) Informatiebehoeften van politiefunctionarissen worden niet alleen gedreven door hun huidige taak, maar ook beïnvloed door de gebeurtenissen en objecten waarop ze zich richten. (3) Politieagenten in het bijzonder moeten zich bewust zijn van informatie met betrekking tot hun persoonlijke veiligheid.

Er bestaat reeds een brede waaier van onderzoeksinspanningen op het gebied van contextbewuste informatiediensten, variërend van diensten voor verkeersregeling, virtuele rondleidingen tot medische assistentie. Er zijn echter maar enkele benaderingen die generieke raamwerken bieden die van toepassing zijn binnen verschillende domeinen. Bovendien is, ondanks het feit dat de meeste onderzoekers het belang erkennen van het gebruik van verschillende contexten, de primair gebruikte contextinformatie nog steeds vaak beperkt tot de locatie van de gebruiker. Daar komt bij dat we zelden onderzoek zien dat zowel de locatie beschouwt als het type van de activiteit waarbij de gebruiker is betrokken. Voor zover wij weten, zijn er onder de contextbewuste systemen die zijn ontworpen voor het rekening houden met de specifieke vereisten van reddingswerkers in kritieke situaties, vrijwel geen die zich bezighouden met het probleem van het bepalen van de relevantie van bepaalde informatie-items in een bepaalde context. Daarnaast worden hun eigenschappen zelden kwantitatief geëvalueerd.

Ons onderzoek wordt gemotiveerd door de bovengenoemde uitdagingen. Wij streven naar het aanbieden van een generieke architectuur dat de gerichte aflevering ondersteunt van gecontextualiseerde informatie die mobiele gebruikers kan helpen om beslissingen te nemen tijdens hun werkzaamheden. In het MOSAIC project, waarbinnen dit onderzoek werd gedaan en dat zich richt op het ontwikkelen van systemen die de omgevingsbewustheid van reddingswerkers verbeteren, worden politieagenten die betrokken zijn bij mobiel politiewerk beschouwd als de eindgebruikers. Door middel van een studie met behulp van een vragenlijst voor deze gebruikers en gebaseerd op een aantal realistische scenario's, hebben we de specifieke informatiebehoeften geïdentificeerd van deze politieagenten. Naar aanleiding van de eisen uit deze studie, ontwierpen we een regelgebaseerde architectuur Contextualized Information Delivery Architecture (CIDA) voor het leveren van relevante informatie die gecontextualiseerd is voor de situatie van de mobiele gebruikers. CIDA, dat bestaat uit (1) informatiemodellen voor de achtergrond informatie, de context en de informatie-items, en (2) een regelexecutiesysteem met de naam Relevance Assessment Rule Engine (RARE) voor de relevantiebeoordeling, heeft twee cruciale kenmerken. Een daarvan is de representatie van de contextuele situatie van de mobiele gebruikers in een ontologiegebaseerd informatiemodel dat uitbreidbaar is en daardoor kan voldoen aan domeinspecifieke eisen. Een andere is de flexibiliteit en aanpasbaarheid van het systeem die gebaseerd is op het gebruik van declaratieve regels in onze regeltaal MRRL. Die regels specificeren welk type informatie relevant is in welke context en kunnen worden aangepast zonder het wijzigen van programmeercode, en vormen zo een principiële manier om het systeem aan te passen aan nieuwe domeinen.

Om de toepasbaarheid van CIDA aan te tonen, ontwikkelden we het Contextualized Relevance Assessment System (CRAS), dat de relevantie van de informatie kan beoordelen door rekening te houden met de contextuele situaties waarin politieagenten zijn betrokken. CRAS werd ontworpen om aan de volgende cruciale eisen te voldoen: (1) het moet op een effectieve manier voldoende relevante informatie selecteren voor politieagenten in een gegeven context, (2) het moet generiek configureerbaar zijn in die zin dat het in staat is om ook min of meer onvoorziene scenario's af te dekken, en (3) het moet eenvoudig kunnen worden aangepast aan de verschillende nieuwe use-cases met bescheiden inspanningen. Om deze eigenschappen te evalueren, construeerden we een collectie van datasets en regelsets gebaseerd op realistische scenario's in samenwerking met de politie. Onze evaluatiemethode volgend, werd CRAS geconfigureerd door de specificatie van de regelsets en toegepast op de gegeven datasets. Voor elke configuratie werden de resultaten geëvalueerd met betrekking tot een gouden standaard in termen van precision en recall in twee modi, streng en soepel. Kwantitatieve analyse van de resultaten laat zien dat het gedrag van CRAS bevredigend is en dat het voldoet aan de gestelde eisen. In het volgende paragrafen vatten we de belangrijkste resultaten van het werk in dit proefschrift samen.

De identificatie en representatie van de informatiebehoeften van politiefunctionarissen in de context van kleinschalige gebeurtenissen. Ondanks de grote hoeveelheid werk op het gebied van contextbewuste diensten die zijn afgestemd op de behoeften van mobiele gebruikers, houden slechts enkele systemen rekening met de specifieke behoeften van politieambtenaren die in een bepaalde context werken. Op basis van ons onderzoek met behulp van vragenlijsten vonden we dat (1) de informatiebehoeften van onze eindgebruikers zeer specifiek zijn voor de gegeven fase waarin zij betrokken zijn, en (2) wanneer zij betrokken zijn bij een bepaald fase zijn bepaalde categorieën van informatie meer relevant dan andere. Nog belangrijker is dat we identificeerden welke categorieën de eindgebruikers nodig hebben in welke fase.

Een set van eisen voor het ontwerp van de architectuur. Op basis van onze waarnemingen bij het voorgaande onderzoek hebben we eisen afgeleid voor een architectuur die het leveren van gecontextualiseerde informatie ondersteunt: (1) de architectuur moet bestaan uit een component die de dynamische aspecten van een gebruikerssituatie kan representeren, met inbegrip van de actuele taak van de gebruiker, de gebeurtenissen die plaatsvinden en de huidige fase, (2) de architectuur moet een component bevatten die in staat is om verschillende soorten van informatie te integreren en te benutten, en (3) de architectuur dient de ontwikkeling te ondersteunen van systemen die de relevantie van de informatie voor een gebruiker kan bepalen in een bepaalde context.

Een architectuur voor gecontextualiseerde informatievoorziening. De meeste van de huidige contextbewuste architecturen en raamwerken zijn nauw verbonden met specifieke domeinen, en slechts enkele benaderingen bieden een flexibele en uitbreidbare architectuur voor de ondersteuning van contextbewuste toepassingen in verschillende domeinen. Geleid door de eisen, hebben we CIDA ontworpen en de functionaliteit gedefinieerd van de afzonderlijke componenten. CIDA bestaat uit (1) een database voor situationele gegevens, oftewel contextdata, (2) een informatie-item database, (3) een regel database, en (4) een regelexecutiesysteem (RARE). CIDA ondersteunt de ontwikkeling van regelgebaseerde systemen die de relevantie kunnen bepalen van de informatie-items, afhankelijk van de contextuele situatie van de mobiele gebruikers.

Een ontologie-gebaseerd context model voor het weergeven van de contextuele situatie van mobiele gebruikers. In vergelijking met de meeste van de bestaande contextmodelleringstechnieken die zich vooral richten op het gebruik van fysieke contexten, beschouwen wij ook de actuele taak en bepaalde gebeurtenissen buiten de gebruikelijke context van ruimte en tijd. We hebben een ontologie-gebaseerd contextmodel opgesteld dat bestaat uit (1) een generieke ontologie dat de basisbegrippen definieert en uitgebreid kan worden voor verschillende domeinen, en (2) een domeinspecifieke ontologie dat de details van de algemene concepten en hun eigenschappen definieert, en gespecialiseerd is voor het domein van mobiel politiewerk.

Een regel-gebaseerd systeem voor contextafhankelijke relevantiebeoordelingen voor het domein van de mobiel politiewerk. Met het doel de haalbaarheid van CIDA te laten zien, ontwikkelden wij CRAS, dat de relevantie kan bepalen van informatie-items naargelang de contextuele situaties van politieagenten. We zijn begonnen met het definiëren van onze regeltaal (MRRL) voor het genereren van een cumulatieve score van een informatie-item voor een bepaalde gebruiker in een bepaalde context. We hebben ook een regelexecutiesysteem geïmplementeerd (RARE) om MRRL regels uit te voeren, wat het configureren van het gedrag van CRAS mogelijk maakt, om het aan te kunnen passen aan verschillende use-cases.

De evaluatie van het systeem op basis van verschillende realistische use-cases. In vergelijking met de huidige technologieën voor het evalueren van contextbewuste systemen, richten wij ons in het bijzonder op de kwantitatieve evaluatie van het regelgebaseerde systeem voor contextuele relevantiebepaling. In navolging van onze evaluatiemethode werd CRAS geëvalueerd voor vier regelsets die werden toegepast op drie datasets in verschillende configuraties. Meer specifiek, om de vraag te beantwoorden of het mogelijk is om CRAS aan te passen aan een toekomstige use-case zonder gebruik te maken gegeven relevantieoordelen voor die use-case, hebben we verschillende methodes gebruikt om twee regelsets te ontwerpen voor het afdekken van een toekomstige use-case: een set bestaande uit scenario-gebaseerde regels, en een andere set bestaande uit oordeelgebaseerde regels. De resultaten in termen van precision en recall met betrekking tot de gouden standaard toonden aan dat: (1) CRAS kan zodanig geconfigureerd worden dat het goed genoeg is voor het selecteren van adequate informatie voor de eindgebruikers gegeven hun context, (2) CRAS is generisch configureerbaar in die zin dat het redelijke prestaties levert als huidige regels onveranderd worden toegepast op toekomstige use-cases; (3) CRAS kan gemakkelijk worden aangepast aan nieuwe use-cases door het toevoegen van extra regels; (4) de uitgebreide regelset voor het aanpassen van CRAS aan een toekomstige use-case is in staat om deze use-case goed af te dekken zonder gebruik te maken van relevantieoordelen voor die use-case; en (5) die extra regels leiden tot een geleidelijke verbetering van het gedrag van CRAS op toekomstige use-cases, zonder een significante verslechtering van de prestaties op reeds eerder afgedekte use-cases.

In dit proefschrift hebben we CIDA ontworpen naar aanleiding van de eisen die zijn vastgesteld in het begin van het onderzoek, zodanig dat het de ontwikkeling ondersteunt van regelgebaseerde systemen voor de beoordeling van de relevantie van de informatie gegeven de huidige context van de gebruiker. We implementeerden CRAS aangepast aan het domein van mobiel politiewerk. Uit de evaluatie bleek dat CRAS voldoet aan de specifieke eisen van de eindgebruikers en daarmee is tevens impliciet de geschiktheid van CIDA aangetoond. Op basis van de conclusies van deze thesis, verwachten we dat CIDA zal worden uitgebreid voor het ondersteunen van de ontwikkeling van regelgebaseerde systemen voor gecontextualiseerde relevantiebeoordeling in verschillende domeinen. In het bijzonder kunnen die systemen eenvoudig worden aangepast aan de verschillende use-cases door het specificeren van de sets van MRRL regels die stapsgewijs uitgebreid worden voor het afdekken van nieuwe use-cases. We verwachten ook dat in navolging van onze evaluatiemethode bepaalde eigenschappen van deze regelgebaseerde systemen kwantitatief zullen worden geëvalueerd op basis van een aantal use-cases.

Summary

Towards Contextualized Information Delivery: A Rule-based Architecture for the Domain of Mobile Police Work

When engaged in activities in a changing environment, the typical mobile users of today need up-to-date information in order to assist their activities. Current web service technologies together with the advances in mobile devices have significantly increased the ability to provide the right information to the right person. An increasing number of mobile users demand adaptable services tailored to their specific requirements in a particular situation. This demand has posed a major challenge for designers and researchers investigating context-awareness: *What are the solutions that enable applications to adapt their behaviour to mobile users' current context but without consuming too much of their attention?*

In contrast to the traditional office work environments, the contextual situations of mobile users are characterized by change and can be described by various dimensions of context, including the physical/external context that can be captured by hardware sensors, such as location, time and speed etc., and the logical/internal context that is related to user's activities, goal and even emotional state. In order to meet specific information needs of mobile users in a given context, context-aware applications should not only detect a change of context, but also determine the relevant information or service which could support their task at hand. Typically, mobile police officers need technical support in the form of information systems tailored to their contextual information needs. These specific requirements pose a great challenge on the development of context-aware systems for supporting mobile police work as: (1) A routine situation of police officers can at any given time evolve into an urgent one. (2) Information needs of police officers are not only driven by their task at hand but also influenced by their targeted events and objects. (3) Police officers in particular need to be aware of information related to their personal safety.

There exists a rich body of research efforts on providing context-aware services, ranging from traffic routing, virtual tour guides to healthcare assistances. However, only a few approaches offer generic frameworks that are applicable to different domains. Moreover, despite the fact that most researchers refer to the importance of using various contexts, the primary context information used today is the user's location. Besides, we rarely see research work that considers both the location and the type of activity that a user is involved in. To our knowledge, among those context-aware systems designed by taking into account the specific requirements of emergency responders in critical situations, almost none of them address the issue of computing of the relevance of information items in a given context. In

addition, they are rarely quantitatively evaluated in terms of their properties.

Our research is motivated by tackling the above challenges. We aim at offering a generic architecture supporting delivery of contextualized information that can assist mobile users to take decisions during their activities. Within the MOSAIC project, in the context of which the presented research was done and which is aimed at developing systems that enhance situation awareness of emergency responders, police officers involved in mobile police work are considered as our end-users. Through a questionnaire-based study aimed at these end-users on the basis of a number of realistic scenarios, we identified the specific information needs of police officers. Following the requirements derived from this study, we designed a rule-based architecture (CIDA) for delivering relevant information contextualized to the situations of mobile users. The main components of CIDA consist of information models for the background information, the context information and the information items, and a rule engine (RARE) for relevance assessment. CIDA was designed to have two crucial features: one is the representation of the contextual situations of mobile users relying on an ontology-based information model, which is extensible for meeting those domain-specific requirements; another one is the flexibility of adaptation, which builds on declarative rules defined in our rule language named MRRL. Those MRRL rules, specifying which type of information to deliver in which context, can be modified independently of the code executing them, thus providing a principled way to adapt systems to new domains.

With the goal of demonstrating the applicability of CIDA, we developed the Contextualized Relevance Assessment System (CRAS) which can assess the relevance of information items by taking into account the contextual situations police officers are involved in. CRAS was implemented to meet the following crucial requirements: (1) it should effectively select adequately relevant information for police officers given their context; (2) it should have generic configurability in the sense that is able to cover different scenarios; and (3) it should be easily adapted to different use cases with modest efforts. In order to evaluate these properties of CRAS, we constructed a set of datasets and rule sets based on realistic scenarios in cooperation with police officers. Following our evaluation method, CRAS was reconfigured by the specification of rule sets and applied on given datasets. For each configuration, the results were evaluated with respect to a gold standard in terms of precision and recall in two modes (i.e. strict and lenient). Quantitative evaluations show that the behavior of CRAS is satisfactory and thus meets the requirements. In the following, we summarize the main results of the work presented in this thesis.

The identification and representation the information needs of police officers in the context of dealing with small-scale events. Despite the large body of work in the area of context-aware services tailored to the needs of mobile users, few efforts take into account the specific needs of police officers acting in a given context. Based on our questionnaire-based study, we found that (1) the information needs of our end-users are highly specific for the given phases in which they are involved; and (2) when being involved in a particular phase, certain categories of information are more relevant than others. More importantly, we identified which categories of information end-users require in which phase.

A set of requirements for the architecture design. According to our observations from the study, we derived the requirements for an architecture supporting delivery of contextualized information as: (1) the architecture should consist of a component that can represent dynamic aspects of a user's situation, including the task at hand, the events that happen and current phase; (2) the architecture should include a component that is able to integrate and exploit different categories of information; and (3) the architecture should support the development of systems which can determine the relevance of information given a user's context.

An architecture for contextualized information delivery. Most of the current context-aware architectures and frameworks are tightly connected to specific domains, and only few approaches offer flexible and extensible architectures for supporting context-aware applications in different domains. Guided by the requirements, we designed CIDA and defined the functionality of single components. CIDA consists of (1) a situational data (i.e. context data) repository; (2) an information item repository; (3) a rule store; and (4) a rule engine (RARE). CIDA supports the development of rule-based systems which can compute the relevance of information items depending on the contextual situations of mobile users.

An ontology-based context model for representing the contextual situations of mobile users. Compared with most of the existing context modelling approaches that focus on using physical contexts, we consider the task at hand and certain events beyond the spatial-temporal context. We established an ontology-based context model which consists of (1) a generic ontology that defines the basic concepts and is extensible to different domains, and (2) a domain-specific ontology that defines the details of general concepts and their properties specialized for the domain of mobile police work.

A rule-based system for contextualized relevance assessment for the domain of mobile police work. With the goal of showing the feasibility of CIDA, we developed CRAS which can assess the relevance of information items according to the contextual situations of police officers. We started by defining our rule language (MRRL) for the purpose of generating a cumulative rating of an information item for a certain user in a given context. We also implemented the rule engine (RARE) to execute MRRL rules, supporting the configuration of the behaviour of CRAS to be adapted to different use cases.

The evaluation of the system on the basis of different and realistic use cases. Compared to the current technology for evaluating context-aware systems, we focus in particular on the quantitative evaluation of those rule-based systems for contextualized relevance assessment. Following our evaluation method, CRAS was evaluated for four rule sets on three datasets with regard to different configurations. More specifically, in order to answer that is it possible to adapt CRAS to a forward use case without relying on the collection of relevance judgements, we used different methods to engineer two sets of rules for covering a forward use case: one set contains *scenario-based* rules and another set contains *rating-based* rules. The results in terms of precision and recall with respect to the gold standard demonstrated that: (1) CRAS can be configured such that it is precise enough to select adequate information for end-users given their context; (2) CRAS has generic configurability in the sense that it provides reasonable performance by applying current rule sets on forward cases; (3) CRAS can be adapted to forward use cases easily by only adding additional rules; (4) the extended rule set for adapting CRAS to a forward use case is able to cover this case without relying on an already known set of relevance judgements; and (5) those additional rules gradually improve the behavior of CRAS on a forward use case while not significantly degrading the performance on backward cases.

In this thesis we designed CIDA following the requirements, such that it supports the development of rule-base systems for assessing the relevance of information according to the user's current context. We implemented CRAS adapted for the domain of mobile police work. The evaluation results showed that CRAS meets the specific requirements of end-users and thus also demonstrated the suitability of CIDA. Based on the conclusions from this thesis, we expect that CIDA will be extended to support the development of rule-based systems for contextualized relevance assessment in different domains. In particular, those systems can be easily adapted to different use cases by specifying the sets of MRRL rules that are incrementally extended for covering forward use cases. We also expect that following our evaluation method certain properties of those rule-based systems will be quantitatively evaluated based on a number of use cases.

Curriculum vitae

Beibei Hu was born on July 19th 1983 in Urumqi, the capital of the Xinjiang Uygur Autonomous Region – China's most western province. She earned her Bachelor of Information Science degree from Nanjing Agriculture University with first class honors in 2004. From 2005 to 2007, she pursued her master's studies in Information Science at Nanjing University supervised by Prof. Xinnin Su, working as a research fellow in the institution of Information Technology of Nanjing University. During this time, she was granted the National Scholarship.

After receiving her Master of Information Science degree in 2007, she joined the department of Software and Computer Technology at Delft University of Technology in the Netherlands as a PhD candidate. Since 2008, she joined the Web Information Systems group lead by Prof. Geert-Jan Houben. During her PhD research, she was involved in the MOSAIC (Multi-Officer System of Agents for Informed Crisis Control) at DECIS-lab (Delft Cooperation on Intelligent Systems Lab), in cooperation with vtsPN (voorziening tot samenwerking Politie Nederland). Her research focuses on offering a generic architecture for delivering contextualized information that can assist mobile users in their decision-making during their specific activities. She is in preparation to submit her works to international journals.