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ENHANCED METHODOLOGY FOR ONTOLOGY DEVELOPMENT

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Abstract. The creation of an initial glossary of terms is a preliminary phase of domain ontology building. Existing methodologies assume that such a glossary has been created by analysing existing documents or using expert knowledge. Some methods have been defined for this step of ontology building; these methods are mostly based on the analysis of existing documents. We propose to utilise the existing pieces of knowledge obtained in the area of object-oriented analysis; the description of a domain structure, behaviour and rules. Domain structure, behaviour and rules all together represent a complex and systematic view of the domain that makes it possible to create a high-quality glossary. This method is demonstrated using the domain of a road traffic system. Our method has been developed as an extension of the well-known METHONTOLOGY method. Our extension is general enough to be relevant for other ontology-building methodologies.

Keywords: Ontology design, initial glossary of terms, transportation

Mathematics Subject Classification 2010: 68P05, 68T30

1 INTRODUCTION

The development of ontology design methodologies has been addressed by many research teams. These researchers made a proposal of the specification of a sequence of steps that result in the formation of ontology. Good overview of different methodologies is provided in [7].

One of the first methodologies, presented in 1995, was developed from the Enterprise Ontology within the TOVE project [15] in the field of enterprise modelling.

Project specification originated from a questionnaire sent to customers. The answers were then formally analysed using the first-order predicate logic. As a result, a knowledge base of objects, their roles and mutual relations, as well as particular business rules have been obtained. This base represents the generic enterprise-oriented ontology.

The KACTUS project was focused on three domains: electrical network, oil production platform and construction design of large ships. The project was presented at the European Conference on Artificial Intelligence [16].

The SENSUS project [13] used an automatic approach to build its ontology base. The ontology was created by extracting knowledge from various sources. The primary source was the WordNets semantic database.

Mylka and Mylka describe the use of ontology for the heterogeneous data integration [10]. Data are stored in heterogeneous database environment, so they are well-structured and fulfil integrity constrains. The ontology is extracted from these heterogeneous sources in an automatic way.

Quite interesting approach to the ontology building is described in [17]. The authors dealt with creation and management of the dynamic Virtual Organisations with special focus on the authorisation of access to resources based on the ontology. They developed the formal model of contract negotiation. Afterwards, they developed the ontology of Virtual Organisation based on this formal model.

Ontology design is also described by authors who use tools such as Protege [11]. They describe the ways how to capture basic concepts in the early phases of an ontology building. They suggest defining the borders of a given domain using competency questions and then creating the list of terms used in the domain.

In our opinion, the problem of searching for relevant terms is rather neglected in the early phases of an ontology design. Moreover, in the following stages of a taxonomy definition, the problem of redundant concepts appears. On the other hand, we have no reliable tools for checking whether some important concepts are not missing. For example, in [1] the iterative way of an ontology building is applied. Yet, in our opinion, this is not an effective solution because the concepts that are not discovered in the very early stage are usually definitely lost. For these reasons, we concentrate on the problem of discovering, as much as possible, a complete list of relevant concepts in the very early stage of an ontology design. To this end, we concentrate on a domain structure and its behavioural rules.

Our objective is to make use of domain-experts experience in order to specify a primary data dictionary without any support of a knowledge engineer. The dictionary can be used as a basis for next steps of an ontology design, as described, for example, in METHONTOLOGY (see [6]).

From our perspective, we consider METHONTOLOGY system [6] as being the most interesting and well-organised one. It is described in detail below.

The common feature of most of these ontology design methodologies is that they do not systematically describe all stages of an ontology development. What remains to be completed is the creation of the initial glossary of terms. This stage is considered crucial for ontology formation and thus it is the focus of our work.

2 METHONTOLOGY METHODOLOGY

As stated above, we sought an appropriate methodology for a systematic ontology development. After examining the various existing methodologies, we observed that none of them meets all our requirements. Therefore, we decided to begin with METHONTOLOGY and enhance the methods used for the *specification phase* in order to create a *glossary of terms*.

Our starting point was the content of ontology (based on [14, 3]) with its basic ontological types. They are inter alia primitive concepts [4], attributes, taxonomies and concept definitions. METHONTOLOGY, which was developed in the Ontology Engineering Group at the Polytechnic University of Madrid [12], is based on these basic ontological types. This method is largely based on IEEE Std 1074-1995. We decided to follow METHONTOLOGY because of its transparent, logical structure and the integrity of its steps, which reflect the process of ontology development. This process includes the following tasks [6]:

- specify ontology,
- build glossary,
- build concept taxonomies,
- build relation diagrams,
- build concept dictionary,
- describe
  - relations,
  - attributes and
  - constants,
- describe
  - formal axioms,
  - rules and
  - instances.

METHONTOLOGY thus describes the sequence of steps that will, in its final stage, determine the basic ontological types. Like most current methodologies, METHONTOLOGY does not provide detailed instructions on how to create the glossary. It also omits instructions on how to select appropriate concepts with regard to the given domain and its tasks. It contains only a brief description of how to proceed in the specification phase, i.e., during *ontology specification*.

3 ONTOLOGY SPECIFICATION

The objective of this first stage is to create a specification document written in natural language, including at least the following [6]:

- the purpose of the ontology, including its intended use, scenarios of use, specifications of end users, etc.,
- the level of formalisation of the implemented ontology,
- the range, including a set of concepts to be represented in the ontology, its characteristics and granularity.

A middle-out approach is recommended for the creation of an ontology specification, allowing a set of terms that should be included in the ontology to be obtained without knowledge of their significance. Grouping the terms into classification trees is also recommended. These steps allow us not only to verify the relevance of ontology terms and seek out missing terms in an early development stage but also to look for synonyms, or even omit redundant terms. Another advantage of this approach is that it allows us to search for terms that should be at the core of future ontology. Consequently, these terms can be generalised or, conversely, specialised to the necessary extent, if needed. The resulting set of terms is much more stable and will require far fewer changes in the future [6].

METHONTOLOGY also recommends a whole range of knowledge acquisition techniques, including different interviews and document analyses. Based on this knowledge, a glossary can be constructed. However, this methodology provides no structured process to obtain a glossary. An intuitive approach is assumed herein, which can resolve this issue.

4 PROPOSED ENHANCEMENT OF METHONTOLOGY METHODOLOGY

The construction of a basic glossary, which has thus far not taken into account the various integrity constraints, must be preceded by a number of steps. As shown by the results of our research, the steps leading to the glossary creation may be (at least in general) specified and systematised. The proposed procedure is divided into several steps, each of which specifies who is privileged to perform it; either a Domain Expert (DE) or a Knowledge Expert (KE).

At the beginning of ontology development the purpose of the ontology must be specified. The next step is to find and collect the terms used to describe a given domain. When taking this step, we attempt to maintain the shareability goal of the created ontology [8]. Identified terms are evaluated with regard to the clarified purpose of the ontology. Subsequently, based on the selected terms, a glossary is generated, which will include a simple list of terms from the given domain (Figure 1). Needless to say, the process preceding the glossary creation is iterative.

It is important to recognise at the very beginning of the ontology development that the domain analysed has both static and dynamic aspects in addition to behaviour rules. The static aspects of the system include the concepts of typical objects and their mutual relationships in the given domain, i.e., aspects that describe *its static structure*. Dynamic aspects include a description of *the system behaviour*, which must respect certain *rules of behaviour*.

The analysis of systems from different perspectives is dealt with, inter alia, using object-oriented analysis. There are a number of different methodologies to perform such an analysis, and they share some general features. These methodologies always attempt to describe the following elements:

- structure of the system,
- behaviour of the system and
- rules of the system behaviour.

Our proposal is based on the same approach. We have therefore designed the following sequence of steps for the creation of a high-quality glossary. The process is shown graphically in Figure 1 and every step of this process is briefly described in the five following paragraphs: *Description, Extraction, Comparison, Search for Basic Terms and Addition of Missing Terms* and *Synonyms/Homonyms*.

Description. For the initial specification which views the system in terms of business logic, we include three kinds of description of the analysed domain:

- description of the structure,
- description of the behaviour and
- description of the behaviour rules.

The *description of the structure* is relatively simple and should contain all the elements of the analysed domain, which will affect, or rather implement, the domain behaviour.

The *description of the behaviour* may be more complicated. It should include a description of specific issues and tasks resolved within the domain, possibly in the form of the use-case scenarios.

The *description of the behaviour rules* should involve all the rules that must be followed by *the system elements in the resolved domain*.

The performance of this step is the responsibility of the DE. Knowledge of the environment qualifies expert to describe and specify the purpose of the domain. We consider it necessary to separate the three descriptions because

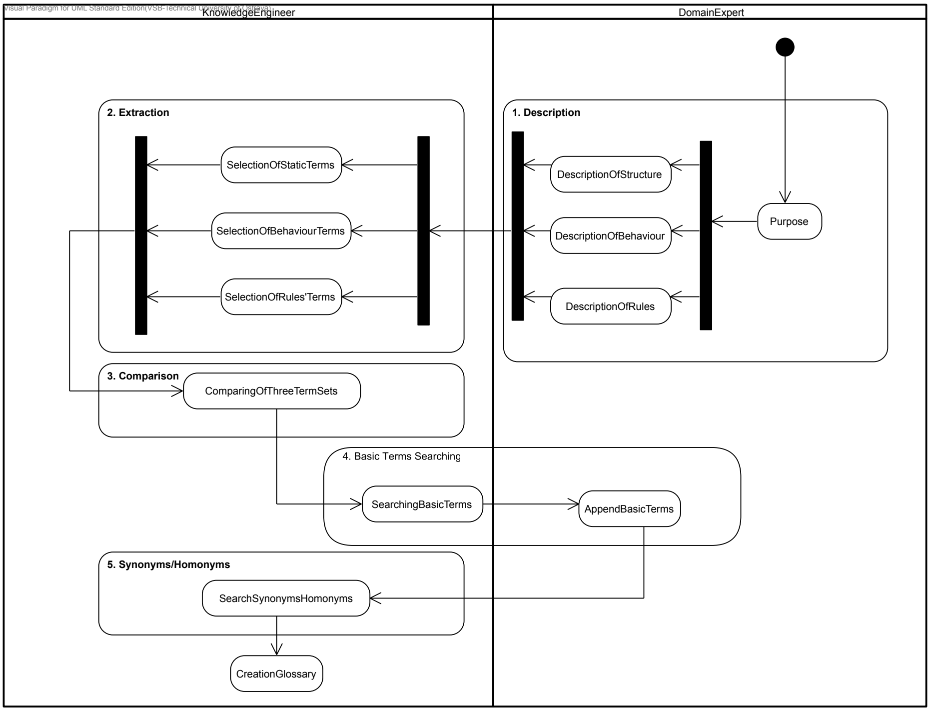

Figure 1. The proposed extension of METHONTOLOGY with described steps

a combined list could lead to omission of important terms. Issues regarding knowledge acquisition and knowledge elicitation are described in detail in [9], for example.

Extraction. (Sets of Terms) The next step aims to extract the set of terms from each description (both single and multiple word terms; these terms will mostly be nouns and verbs) which convey information related to the domain. This step generates three independent sets of terms that do not initially appear to overlap. For subsequent processing, it is important to alphabetise the terms. We will maintain any duplicity between the lists in this step. We assume full responsibility of the KE, of course, with subsequent control from the DE.

Comparison. (Sets of Terms) Subsequently, we will compare these three sets of terms, for example, using a table with three columns. Each column represents one list. The entire table will be arranged alphabetically such that each row contains the terms used in multiple descriptions (i.e., columns). If there is no repetition of a given term in another description (i.e., in another column), we will leave this column line blank. The final table shows that if we selected only one description for the terms used, the result would never be sufficiently representative. Expertise of the KE is expected at this step.

Search for Basic Terms and Addition of Missing Terms. We proceed to search for the particular basic terms that form multiple-word terms and group them into particular hierarchies. If a multiple-word term is unique, it may be introduced as one term (e.g., *the intended direction of continuation after the intersection*). Next, the terms that are not included in the original description but logically belong to the list are added. The rules of addition are based on analogy (e.g., the term *to the right* can be supplemented with the term *to the left*). We consider this step important because it strongly affects completeness of the glossary. This step demands cooperation of the KE and DE.

Synonyms/Homonyms. Eventually, we will search for synonyms and homonyms and group them together. Synonyms are given in succession on one line, separated by commas. First, we will use the preferred term. Homonyms are mentioned on separate lines. Expertise of the KE is presupposed here.

5 CASE STUDY

The process described below is demonstrated by a case study of a *road transport system*. Result of the exemplified process is represented by the desired Glossary of terms of an ontology *describing road infrastructure and vehicle movement*.

Step 1: Description. Domain experts create the system specification. They can use the methods proposed in METHONTOLOGY to fulfill the task. Description of the purpose, *static view*, *dynamic view* and *behavioural rules* are presented.

System Purpose. The road transport system carries people and goods on the Earth's surface using vehicles moving on its designated road infrastructure. This infrastructure crosses the infrastructure designated for pedestrians in specific locations. The road infrastructure traffic follows simple rules and is governed by static traffic signs.

Description of Structure. The road infrastructure is composed of intersections and road sections. The road section is composed of traffic lanes. A dividing and/or merging section before the intersection is considered a special section of the road, whose lanes have a specified direction of travel and turning direction. Individual road sections are connected by either intersections (merging of three or more sections) or junctions (merging of two road sections, generally with different numbers of lanes). We consider the road sections to be one-way, i.e., containing lanes passable in only one direction.

The pedestrian crossings may be marked on the road infrastructure.

Some cars are moving on the road infrastructure.

Description of Behaviour.

- *Situation*: A car is moving on a straight section and it is approaching a slower car.
- *Reaction activities*: The car then investigates whether there is another vehicle in the left-hand lane that could be limited or endangered by its movement. As long as there is none, the approaching car turns on its left blinker, crosses into the left lane, turns off the blinker, passes the slower car, turns on its right blinker, merges into the right lane and turns its blinker off. Otherwise, the car slows down to match the speed of the slower car and follows it in a safe distance.
- *Situation*: A car is moving on a straight section and it is approaching a pedestrian crossing.
- *Reaction activities*: The car investigates whether any pedestrians are crossing and whether a pedestrian standing on the pavement intends to cross the road. Provided s/he does not, the car continues driving. Otherwise, the car reduces its speed so that the pedestrians can cross safely. If necessary, the vehicle stops before the crossing and continues after the pedestrian(s) pass.
- *Situation*: A car is moving along the main road; it is approaching a "T"-shaped intersection (i.e., the main road continues straight, the minor road intersects from the right in the direction of the car movement; there are no pedestrian crossings at the intersection) and intends to turn right.
- *Reaction activities*: Thus there is no need to give priority to anything. The car turns on its right blinker at an appropriate distance from the intersection, reduces its speed so that it can turn safely, and finally makes the turn. The car turns off its blinker and accelerates after passing the intersection.

Description of Behaviour Rules. Cars moving on the road infrastructure follow these simple rules:

- no more than one car can occupy a given space location,
- each car moves in just one traffic lane,
- each car uses the right-most traffic lane when possible,
- cars must not ride in a road section with opposite direction of travel (i.e., into the contra-flow lane),
- cars maintain the maximum speed allowed in a given location when possible,
- cars must not exceed the maximum speed limit,
- cars must respect the direction of travel and the turning direction specified for the lane
- before an intersection, cars move into the traffic lane that corresponds to the intended direction of continuation after an intersection,
- pedestrians may only move on pedestrian crossings,

- each car is required to give priority to a pedestrian who indicates his/her intention to cross a pedestrian crossing.

Step 2: Extraction of the Sets of Terms. The KE selects a set of terms from the given descriptions. Each of the sets is then alphabetised in the appropriate column (see Table 1).

Step 3: Comparison of Sets of Terms. Now we compare the above-obtained three sets of terms. To achieve our goal, we will use a simple table in which each column represents one list. The entire table will then be arranged alphabetically so that each line contains the identical terms used in multiple descriptions. If there is no identical term for a given term in another description, we will leave this cell blank (Table 2).

The table shows that if we selected only one of the descriptions, the resulting set of terms would never be sufficiently representative.

The suggested procedure is simple, and its result proves that the primary specification must be divided into three parts (description of structure, behaviour and behavioural rules). Grouping of the same terms into a row results in groups of terms that are semantically close (see the group connected to the terms *pedestrian* and *pedestrian crossing*), and we can understand these groups as the base of taxonomy.

The result of this step illustrates that commonly applied procedures of knowledge mining – interviews or automatic text processing – might not detect all important terms. The suggested approach limits possible problems during knowledge mining using common techniques [9]. The result can be seen in the comparison given in Table 2.

Step 4: Search for Basic Terms and Addition of Missing Terms. We search for the individual basic terms, which form the multiple-word terms. If there is a unique multiple-word collocation, it can be used as one term (e.g., *the intended direction of continuation after the intersection*).

Moreover, the terms not included in the original description, but logically belonging to the list, are added. This step requires close cooperation of the KE and DE. For example, it is typical to use the rule *turn to the right* in traffic. Although the term *turn to the left* was not specified in the description, it is added to the set of terms because it is logically implied from the described domain. This step can be treated as a verification mechanism of primary specifications.

Such terms are emphasised in Table 3.

Step 5: Search for Synonyms and Homonyms. We identify synonyms and homonyms, which are then grouped together; other terms are also included in Table 4). In the next step (Table 5), synonyms are entered in succession on one line and separated by commas (e.g., *car/vehicle*). The first term is the preferred term. Homonyms are recorded on separate lines (e.g., *turn/turn*). The other terms are recorded on separate lines (e.g., *be located, place*).

Set of terms describing		
the static side	*the dynamic side*	*the rules*
car,	appropriate distance,	*car*,
direction of travel,	*car*,	direction of travel,
direction of turning,	catch up,	drive,
dividing and/or merging section,	continue on driving,	enforced,
intersection,	cross into the left lane,	exceed,
junction,	cross safely,	give way,
one-way,	cross,	intended direction of continuation,
pedestrian crossing,	determine,	*intersection*,
pedestrian,	drive,	maximum car speed-limit currently permitted,
place,	endanger,	maximum speed limit,
road infrastructure,	give way,	motion,
road section,	increase speed,	move into the traffic lane,
traffic lane	indicate intention to cross the road,	move,
	intended direction of continuation after an intersection,	pedestrian crossing,
	intention,	pedestrian,
	left lane,	place,
	limit,	respect,
	main road,	right-most traffic lane,
	merge into the right lane,	specified,
	minor road,	traffic lane,
	overtake,	try,
	pavement,	turning
	pedestrian crossing,	
	pedestrian,	
	reduce speed,	
	safe distance,	
	section,	
	side lane,	
	slower moving car	
	speed,	
	stop vehicle,	
	straight section,	
	“T”-shaped intersection,	
	turn blinker off,	
	turn on a left blinker,	
	turn on a right blinker,	
	turn right,	
	turn safely,	
	turn	

Table 1. Selected sets of terms after extraction. Emphasised terms – car and intersection – foresee next step.

Set of terms describing		
the static side	*the dynamic side*	*the rules*
	appropriate distance	
car	car	car
	catch up	
	continue on driving	
	cross	
	cross into the left lane	
	cross safely	
	determine	
direction of travel		direction of travel
direction of turning		
	drive	drive
dividing and/or merging section		
	endanger	
		enforced
		exceed
	give way	give way
	increase speed	
...	...	...
		maximum car speed-limit currently permitted
		maximum speed limit
...	...	...
place		place
	reduce speed	
		respect
		right-most traffic lane
...	...	...
	speed	
	stop vehicle	
	straight section	
	"T"-shaped intersection	
traffic lane		traffic lane
		try
	turn blinker off	
	turn on a left blinker	
	turn on a right blinker	
	turn right	
	turn safely	
	turn	
		turning

Table 2. Comparison of the sets of terms (abridged)

Term	*Term used in the studied domain*
car	= vehicle?
cross	
– safely	
place	= *be located*?
speed	
– maximum – permitted – road	
– car	
– reduce	= *slow down*?
– increase	= *speed up*?
turn	
– safely	
– to the right	
– to the left	*added term*
turn	
– blinker – on	
– off	
...	

Table 3. Terms selected from Table 1 (abridged)

We can obtain the base of the glossary after this procedure (Table 5) and then continue using the next steps described in METHONTOLOGY, which processes the glossary.

The presented procedure is based on experience gained from the design of systems using object-oriented analyses. Lexical analysis of input data (description of domain, standards, legislation, etc.) cannot guarantee the identification of all terms. Input text may not contain all crucial terms for system development. It can be observed by Step 3, Comparison, and Step 4, Search and Add. These steps result in verification and possible completion of the set of terms even before the "Glossary of terms" is established and processed.

The result of our process is a glossary, which may already serve as a sufficiently representative input into METHONTOLOGY.

6 DISCUSSION

The methodologies designed to develop ontologies usually assume that a glossary would be primarily generated intuitively, based on the studies and analyses of various documents related to the described domain and possibly interviews with experts in

Term	*Equivalent?*	*Syn./Hom.*
car	= vehicle	synonym
cross		
– safely		
place	= *be located*?	no
speed		
– maximum		
– permitted		
– road		
– car		
– reduce	= *slow down*?	synonym
– increase	= *speed up*?	synonym
turn		homonym
– safely		
– to the right		
– to the left		
turn		homonym
– blinker – on		
– off		
...		

Table 4. Evaluation of synonyms and homonyms (abridged)

the field. Our objective is to organise this process in a systematic way. Our method draws on experience obtained from object-oriented system analysis. The object-oriented approach deals with similar tasks, namely the selection of appropriate types of objects which represent the system under scrutiny, and the implementation of the system behaviour while respecting certain rules and constraints. At the beginning of the specification document generation process we therefore proposed compiling three different textual descriptions of a domain of interest based on the obtained knowledge: *the descriptions of the structure*, *the behaviour*, and *the rules of the domain*. Based on these three descriptions, three sets of terms can be composed that concern different aspects of the studied domain. Conversely, these sets also overlap as the studied aspects are not independent of each other. Based on a simple comparison, it can be demonstrated that using only one of these descriptions, the domain would not be sufficiently and accurately represented. The highest accuracy can only be achieved by comparing and grouping these three kinds of descriptions. In this way one can identify additional terms that have not emerged from initial descriptions but can be added, for example, using an analogy. One can also identify a synonym to select the term that will continue to be used as a principal term.

Term
be located
car, *vehicle*
cross – safely
place
speed – maximum – permitted – road – car – reduce, *slow down* – increase, *speed up*
turn – safely – to the right – to the left
turn – blinker – on – off
...

Table 5. Grouping of synonyms and homonyms (abridged)

However, a systematic reduction of the terms is not recommended at this stage. These terms should be retained for further steps of ontology development.

It is obvious that the quality and in particular completeness of the resulting glossary depend on the quality and completeness of the initial descriptions. However, compilation of these descriptions can be assigned to the experts of the given domain. The compilation of textual descriptions may be welcomed by these experts as an easier task than having to select, in a debate, the single terms not directly linked to other terms, the tasks being solved in the domain, or the rules.

A similar approach is presented in [2]. This work developed a new methodology of ontology building, the Unified Process for Ontology building (UPON), based on software engineering experiences. The methodology is based on application of unified process well known from object-oriented analysis and software design. This approach is well suited for cases when software engineering is the domain of interest. The users of such a methodology should be experts in software engineering, namely in the unified process of software development. However, it is unclear how often this is the case. Ontology is usually created by different types of experts (from the fields of philosophy, logic, artificial intelligence, etc.) who have experience with traditional methodologies. Our approach is a compromise between these two approaches; it augments traditional ontology building methodologies with the suitable principles of an object-oriented approach. Therefore, we consider our method suitable for traditional ontologists.

7 CONCLUSION

This paper suggests an extension of the METHONTOLOGY methodology; the extension is focused on a clearly defined course of steps in order to create a representative set of terms expressing fundamental primitive concepts of the given domain at the early stages of an ontology development. Then, the list of these concepts may be processed by traditional methods of the METHONTOLOGY methodology. Moreover, our method is general and thus applicable within other methodologies which always begin with a glossary.

We tested the method when creating a prototype of a road-traffic system. The system has been developed within the project No. 1ET101940420 "Logic and Artificial Intelligence for Multi-Agent Systems" supported by the "Information Society" program of the Czech Academy of Sciences. The goal of the project was the research of information technologies needed for coordination of autonomous intelligent agents in extraordinary or emergency situations. There are currently a number of methodologies to develop ontologies. Their common disadvantage is that they do not deal with systematic generation of an initial glossary.

Our work is theoretical and responds to practical problems we encountered when creating ontology for a traffic multi-agent system. We were unable to solve problems related to the inaccuracy of terms dictionary systematically. That is why we searched for a suitable method how to create the terms dictionary. This article describes the method.

Research within the project was originally focused on three basic areas: process management including the specification and prediction of critical situations, knowledge and data management, communication and infrastructure. As the theoretical background needed to pursue research in all three areas the expressive system of Transparent Intensional Logic [5] was used. We concentrated on the development of a platform that would make it possible to adequately represent knowledge and communication in a multi-agent world. A rational agent in the multi-agent world should be able to reason about the world (consider what holds true and what does not), about its own cognitive state and the state of its fellow agents. Since agents have to communicate, react to particular events in the outer world, learn by experience and be less or more intelligent, a powerful logical tool is of a great importance.

To achieve these goals, a well-designed ontology is necessary. Thus a new group focused on ontology research was established. A multi-agent traffic system was chosen as a pilot project. We developed a prototype of this system, the fundamental part of which was the *road-traffic ontology*. When building up this ontology, we applied the above-described method of creating a fundamental set of primitive concepts within the initial stage of an ontology building.

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