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Context-Based Decision-Making for Virtual Soccer Players

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Abstract. This article introduces a decision-making model for virtual agents evolving in dynamic and collaborative situations. In order to enhance behaviour credibility and its description, the agent decision-making model is based on notions such as context and case-based reasoning, that are similar to the human ones. After an introduction to dynamic and collaborative situations, we present a formal definition of context adapted to our framework. The next part describes the decision-making process. This one relies on the case identification thanks to a search graph algorithm. The last part of this paper illustrates our purpose in the team sport framework, with a result issued from our simulation.

1 Introduction

Our works focus on collaboration learning in dynamic situations [1]. This is done through the developpement of a virtual environment for training (VET), where humans are immersed in a virtual world with autonomous agents; they are then confronted to situations reflecting reality. Humans are represented by avatars in the simulation, Thus, they have then to collaborate with virtual agents to achieve a task. In this paper, we present a way to make virtual agents autonomous, where information retrieval is based on context notion. As context is domain dependent, we decide to follow an application example. We illustrate an application of our model in soccer domain. This VET, called CoPeFoot (Collective Perceptions in Football), is populated with virtual agents. We introduce a decision-making mechanism for these virtual agents.

We begin with the postulate that if agents could have the same mechanisms that those identified by psychologists, we can both obtain a credible behaviour and a way to make decision-making more explicit. Context is one relevant characteristic identified by psychologist in sport decision-making [2]. The possibility offers by manipulating it in computational models should allow to simulate characteristic behaviours with different expertise levels. Another interesting point is the possibility to test cognitive assumptions in simulated environment, such as context influence in a collective behaviour.

Papers dedicated to context in artificial intelligence are numerous[3,4,5]. Moreover, this concept is very large. In this studyy, we retain the definition given in [6], that defines context as *a collection of significant conditions and surrounding influences that make a situation unique and comprehensible.* This definition is close to the sport psychologists one that considers context as a toolkit for an actor, in situation, to take a decision

In the framework of autonomous agents, context is considered as a perception filter. Information are not necessarily relevant, neither in the same manner nor at the same time. An expert defines relevant information according to its point of view. Thanks to this expertise, agent has a perception catalog. It has to find perceptions and construct them when it is in situation.

Moreover, in our approach, agent decision-making relies on the case-based reasoning paradigm [7]. It is based on the assumption that a problem can be efficiently solved by reusing knowledge about already solved cases. Association between context and case-based reasoning has been introduced in [4] and called context-based reasoning. This new paradigm has been used in [5] to implement a personal assistant. Case-based reasoning has been used to set up behaviour of autonomous player for the RoboCup [8]; our aim is a bit different because we do not look for the best optimisation but we try to make the decision-making more explicit.

Our representation allows to put in place a search graph algorithm to find most similar cases, moreover it allows to have the most explicit case base. This point is very important, case description and reasoning have to be explicit because the trainer should be able to define agents behaviour and to set easily up pedagogical tools.

Building such simulator implies some important technical constraints. The first one relies on the number of simulated agents. The decision-making process has to be costless in order to be duplicated to simulate up to 22 players. A second constraint is due to the real-time aspect. Decision-making of virtual agents is done under time constraints; moreover agents reaction to context movement has to be visually and temporally credible. Consequently, an agent has to be able to determine the most relevant action at any moment of the simulation. We are using an *anytime* algorithm [9] based on a description of case base as a tree. Moreover, we have to simulate the environment and perceptions for each agent. To is done by using a tool AReVi [10][1], a C++ framework, allowing 3D simulations based on a multi agent approach. Figure 1 illustrates a simulation loop of our application CoPeFoot (Collective Perception in Football). AReVi provides player physical perceptions. Context plays the role of an active filter on these perceptions in order to give a semantic according to the domain (soccer in our case). This contextual perception is the base of the identification process that retrieves typical cases, these are defined either by a domain expert either by imitating situation already solved in the simulator.

This document is structured as follows : the next part deals with theoretical background of our work. In the third part, we detail our definition of context.

[1] http://sourceforge.net/projects/arevi/

The fourth part focuses on decision-making process of our agents. Finally we present results in which we change the number and the type of context in each agent decision-making.

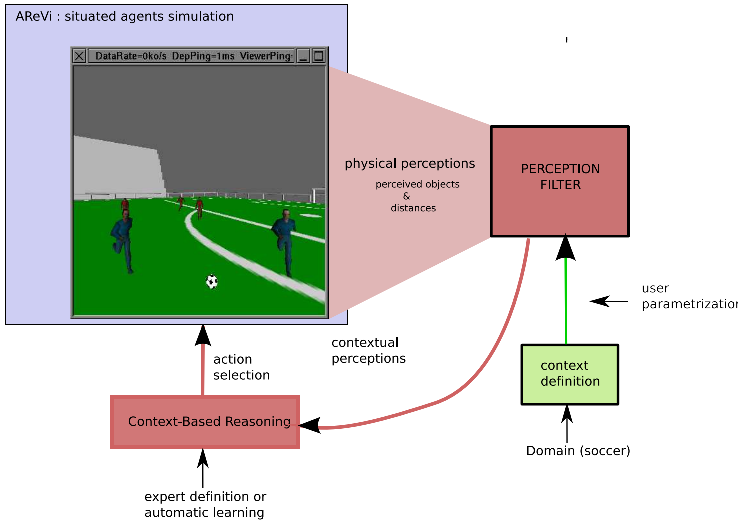

Fig. 1. Context-Based Reasoning in CoPeFoot

2 Collaborative and dynamic situation in sport

Dynamic and collaborative situations can be found in various domains of teamwork with time constraints (rescue, security) or in collective sports [1]. We decided to keep the latter to illustrate our approach.

More precisely, a dynamic and collaborative situation can be characterized by the following points [11] :

- Various protagonists must interact in a common environment and have to solve a problem. The environment state and the protagonists one form the situation. A collaboration between protagonists is needed in order to solve the problem.
- Situation data can be interpreted according to the protagonists point of view. Those agents are able to adopt epistemic point of view on the situation according to their roles.
- Situation interpretation allows a decision-making that depends on protagonists objectives. The decision-making is materialized by an action or interaction. An action modifies the environment.

– The situation is dynamical. Elements, that are taken into account to take a decision, are modified during the resolution. This evolution is function of the protagonists behaviour, but it is almost linked to the environment. The later is modified quickly, so the decision has to be taken following the time constraint. It is not possible to have complex negociation mechanisms. This does not exclude all communications type, but it is simply brief and often non verbal.

The figure 2 shows a simulation example of a simple collaborative and dynamic situation. The first figure represents the situation: Players *'me'* and *a* are in the same team, their aim is to score. Players *b* and *c* are their opponents.Player *'me'* has the ball. The second figure illustrates a possible solution which consists for the player *'me'* in making a pass to *a*, running behind *b* and calling for the ball. Player *a* passes the ball, and *'me'* just has to score. The solution depicted corresponds to a well known collaboration in soccer called *pass and go*. The last figure is a 3D representation taken from our simulator.

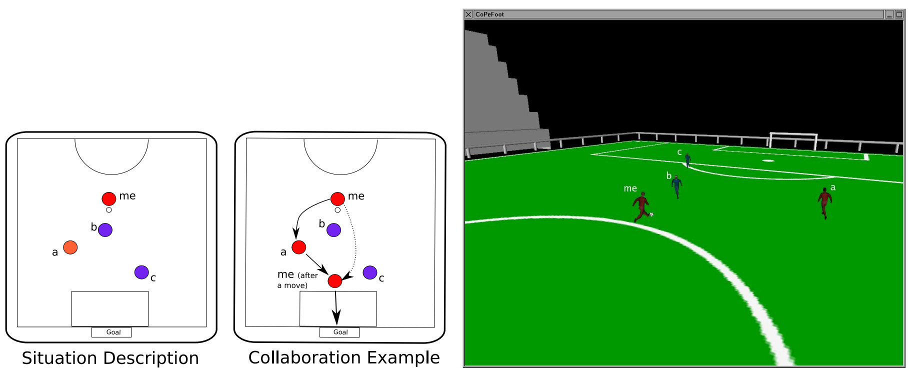

Fig. 2. Example of dynamic situation and its 3D representation in CoPeFoot

3 Context

To make virtual agents autonomous, one can explore two ways. The first one consists of an exhaustive explanation of behavioural rules of agent, relatively to a global representation of the problem. This is suggested by the use of informed environment [12]. The main problem is exhaustiveness for simulation as complex as human behaviour [13].

The second way consists in modelling agents with internal values with no direct link with the environment. The agent can build its own exteriority by the way of its own world representation [14]. The problem of this approach is the need of interactions abstraction between the virtual environment and its internal values. It is hard to generate complex autonomous behaviours without direct explicit link with environment.

We argue that context-based reasoning can be an alternative between these two ways. It allows a definition of abstractions on perceptions and actions of the agent to let it evolve in an unpredictable environment. It allows to give agent information with a rich semantic as provided by an informed environment. One can take an example of verbalization about an action to define contextual elements. Trainer tells: *If a player has the ball and a partner is closer to the goal than him, he has to pass him the ball unless he is marked* . In the same way a psychologist speaks about the link between the expertise level and the number of context taken into account. We try to formalize this type of knowledge thanks to our contexts. The next part details our context formalization and modelling for our virtual agents.

3.1 Context Structure

An agent context is a set of perceptions. This context stands for the agent own representation of the world. Agent decides what action should be executed thanks to its *personal* context. This last is built with all others contexts of the agent as shown on the figure 3. It shows contexts that an agent can have, but not all contexts are its own, some of them can belong to the team or a group in which agent can play a role. Each of these contexts will be explicitly described in the next part. This decomposition allows to enhance our model modularity on the context number. It influences the decision-making and a better adaptation of our model for other implementation than the one introduced here. Thus, psychologists can add or remove a context to estimate its role in collaborative decision-making. Trainer or psychologists can choose the number and type of perception to simulate different expertise levels.

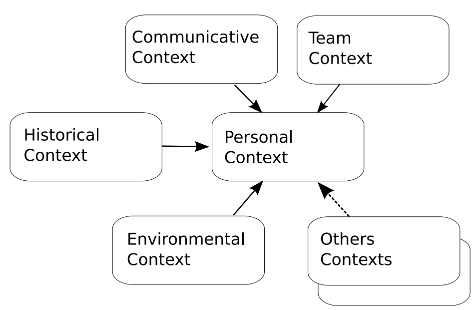

Fig. 3. Personal context building

3.2 Contexts definition and role

In our framework, perceptions have been defined thanks to domain expert help. We are working with sport psychologists, they have done some studies with real soccer players [15]. They have conclued that the basis perceptions of a soccer player are those we present here. In our model, a perception can be seen as a predicate which can be satisfied or not. The set of perceptions predicates is called P_{perc} in the rest of this paper. Predicate evaluation is a request to the perception filter which enumerate all conditions that satisfy it. For example, `hasBall(J)` is a perception. This one is true for a player `p` if a player `J` has the ball and `p` has perceived `J` and is aware of this fact. This is due to the fact that a player views only a part of the field. The request is done in a PROLOG manner, it means that the filter answers all possible values from the simulation at this moment. For this perception, the corresponding value is the player identifier (*i.e* in CoPeFoot: Player.2). If the ball is not perceived by the player, the request will not succeed.

Environmental context is composed of every perception linked to physical environment, for a large part, perceptions linked to the agent field of view. Now, environmental perceptions that are implemented are presented here:

- `distance(+`[2]`CtxObjet3D1, +CtxObjet3D2, ?D)`, true if graphical objects `CtxObjet3D1` and `CtxObjet3D2` are perceived and are at a distance `D`. `D` is a symbolic and qualitative value and $D \in \{nearest, near, far, further\}$
- `relativePosition(+CtxObject3D1, +CtxObject3D2, ?Value)`, true if `Value` represents the position of object `CtxObject3D1` relatively to `CtxObject3D2`. This symbolic value belongs to $\{right, left, front, behind\}$
- `hasBall(?P)`, true if the player `P` has the ball ($\{\exists_{perc}{}^{3}(P \in \mathit{Player}, B \in \mathit{Ball}) : \mathit{distance}(P, B, D) \wedge D = \mathit{nearest}\}$).

Communicative context is made up of relevant information coming from messages sent by other agents of the simulation, these can be another player or the referee. Perceptions stored in this context are not messages themselves, but their significances. As visual perceptions, their validity is limited in time, which can be adjusted depending on the perception type. Implemented perceptions are:

- `callForBall(?X)`, true if `X` is a partner and he has called for the ball.
- `callForSupport(?X)`, true if `X` is a partner that has asked for support.

Team context does not directly belong to an agent, but to its team. This context is made up of every perception that are shared by every player of the team. Perceptions are:

- `partner(?J)`, true if the perceived player `J` is in the same team (formally $\{\exists_{perc} J \in \mathit{Player} : \mathit{J.team} = \mathit{agent.team}\}$) [4], where *agent* is the perceiving player.

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[2] We are using the standard PROLOG notation which allows to indicate if an attribute value is necessarily (+) or if it does not matter (?).

[3] $\exists_{perc}$ means that it exists one perceived element.

[4] Expression `X.Y` refers to the attribute `Y` of object `X`.

- `opponent(?P)`, true if the perceived player `P` is an opponent (formally $\{\exists_{perc} J \in Player : J.team \neq agent.team\}$)
- `isOnAttack(?X)` true if the team of player `X` is on attack. (formally $\{\exists_{perc} J : \{J.team = X.team \wedge HasBall(J)\}\}$)
- `numericalRapport(+X, ?N)` true if `N` is the ratio between the number of players on field in the two teams. For a team `X`, the value belongs to *{weak, equal, strong }*

Historical context allows agent to have a representation of the match. It corresponds to the previous agent action and some relevant parts of the match evolution. These predicates are:

- `lastAction(+X,?A)`, true if `A` is the last action done by player `X`.
- `timePressure(?T)`, true if `T` is the time before the end of the game, value belongs to *{a lot, enough, few, finishing }*.
- `score(?S)`, true if `S` is a value indicating the actual score in a qualitative manner, value can be *{win, equality, loose}*

As mentionned, the number of our contexts and perceptions are not exhaustive. Thus, the match data could be more refined in order to take into account more previous relevant actions. It can be useful to introduce a group notion during a short period to enhance collaboration. This work should be seen as a base to evaluate context relevance to simulate human behaviour in virtual environment. A second phase of this project consists in increasing the number of contexts and perceptions.

4 Decision-making

Agent decision-making relies on context-based reasoning paradigm [4,5]. Case-based reasoning is often described as a five steps cycle consisting in elaborating, retrieving, reusing, revising and retaining. In the previous part, we have defined how the personal context is built, this corresponds to the elaboration of problem to solve, the first step of the CBR cycle. Revising and retaining is not treated in this paper, but they are one of our goal. This part focuses on the case description and more precisely on the identification mechanism and cases adaptation.

4.1 Cases representation

Cases are stored in a case base. In our approach, base is a tree. Each case is a path from the root to a node. Each node is a perception predicate evaluation. Each node has a table characterizing perception weight for each case in which it appears (figure 4). This weight reflects the importance of the associated perception for this case. Each edge leaving a node contains a possible value of one variable of this predicate (figure 5). This edge allows to go from a perception of a case to the following one.

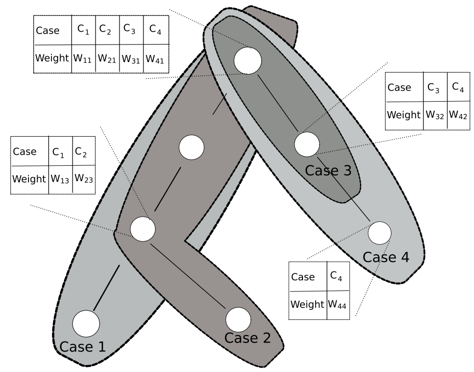

Fig. 4. Each case is a Branch of the tree and has a pertinence weight for each node.

Formally, the tree called $TreeCase$ is a triplet: $TreeCase = \{N, E, C\}$. Where N is nodes set, E edges set and C the cases set. Each case is a branch of the tree associated to an action: $\{\forall c_i \in C : c_i = \{b_i, a_i\}\}$ where $b_i \subseteq N^j$ (where j is the branch depth) and a_i is an action.

Each node is a triplet $\{\forall n_i \in N : n_i = \{pred_i, range_i, pert_i\}\}$ where $pred_i \in P_{perc}$ and $range_i \in I\!N$. $range_i$ represents the range of the variable to be tested. On figure 5, for the node n_3, $range_3$ corresponds to `D`. Indeed, $pert_i$ is a table representing couples $\{c_k, w_{ki}\}$ where c_k is a case in which actual perception plays a role ($n_i \in c_k$) and $w_{ki} \in I\!R$ is $pred_i$ weight in the c_k description. Each edge $e_j \in E$ is a test $e_j = \{cond_j, value_j\}$, where $cond_j$ is an operator $cond_j \in \{=, \neq\}$ and $value_j$ is one of the possible values for $range_i$ argument of the predicate $pred_i$.
That is illustrated on the figure 5. Predicate of node n_1 is `hasBall(X)`, edge e_1 is an equality test on the first argument. Constant *'me'* is one of the possible values for argument `X`(representing agent taking decision). In the same way, edge e_4 stands for the third argument of predicate `distance`. *'far'* is one of the possible value for this argument, as noticed in section 3.2. Notice two interesting points : edge e_3 does not correspond to any test and allows just to identify a partner `W`. Second point concerns edges e_1 and e_3 which tests are the same. This can be possible thanks to case representation, a case is a branch or a sub-branch of the tree. Some branches representing different cases can have common perceptions.

This representation has several advantages presented here :

- It can be used as a decision tree allowing an *anytime* identification of perceived situation (case) during simulation as shown in section 4.2.
- It offers a generic abstract representation thanks to variables and predicates utilisation. This mechanism allows to identify an abstract context stored in the base with an agent concrete context. It prevents from a bigger number of

cases in our case base by avoiding symmetry between cases. An unification process allows to affect value to variable as shown in section 4.2.

– It allows to model a generic decision-making. Indeed, action and corresponding case use the same variables. For example, if a previous variable `X` has been unified with player *Player*.4 and the corresponding action is `pass(X)`, agent makes a pass to *Player*.4.

Decision-making simulation credibility depends on tree description. We use two different ways to do so :

1. Expert can specify nodes and edges of the tree, he has to order the tree. To do so, we are currently working with soccer specialists.
2. The second way is based on observation learning. In this case, agent looks how human avatar reacts in simulator and imitates it. Human shows his reaction according to the different situations. A treatment is necessarily to correct mistakes in the tree, this algorithm is based on perception statistic and allows to reorder tree. Some attempt to learn context by observation has already be done, such in [16].
   This learning phase is currently developed and is not detailed in this paper.

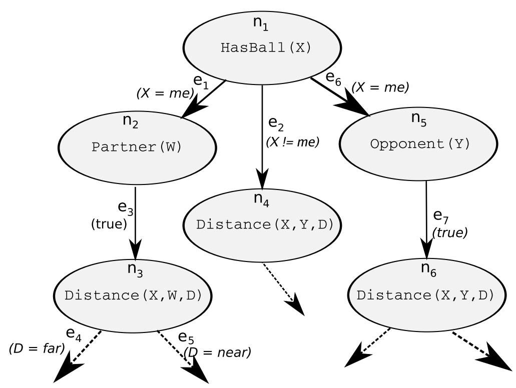

Fig. 5. Case Base representation

4.2 Retrieving a case

Retrieving a case in the base implies to solve the following problems :

– The first step consists of instantiation of tree variable with constants issued from the simulation. Once we have the personal context of the agent, we have to find a perception matching the one of the tree root. We say that a perception is matching when we can unify perceptive predicate with a branch in the graph. If the agent perception and the root one match, we have to continue the tree search. In order to know what is the next perception to test, we are searching correct values of edges leaving the current node to determine next nodes to visit. This instantiation is done with an order defined by the tree. Thus, in the previous example, predicate `hasBall(X)`, according to the simulation state, is unified with the value of the player that has the ball. If the variable is *'me'* (agent who takes the decision), the following node to visit will be n_2. Predicate `partner(W)` is called and try to be unified. Search continues, in the same way, with the node n_5 with the evaluation of the predicate `opponent(Y)`. For the left part of the tree, if a partner has been identified, node n_3 will be activated. Predicate `distance(X,W,D)` has to be evaluated, value of `X` and `Y` are already known, the variable `D` will be unified. A rational search would need a backtracking method to evaluate all possible partners corresponding to `W`. In reality, such exhaustiveness does not correspond to human decision-making. Moreover, it will be technically confronted to research time incompatible with real-time simulation. Selected heuristic consists in unifying variables according to graphical objects relative positions with the agent. This solution is the most pragmatic one, it looks like common sense : nearest objects are the first perceived.

– Next step is the relevance evaluation of the case and selection. Remember that we can have more that one corresponding path.

  To select the best case in the tree, every corresponding case has a global score. It corresponds to the sum of every perception of the case with a reward or a penalty as explained later.

$$score_{c_k} = \{ \sum_{\{i:n_i \in c_k\}} w_k i \} + bonus_k$$

  This score is a compromise between search depth in the tree and the relevance of each perception associated with the case. At the end, for each case every perception weight are summed and the case with the higher score is chosen. Weights allow to take a decision at any time by selecting the case with the highest score. Next algorithm illustrates this purpose. For each evaluated node, the case score is updated by adding the weight of the current perception, this is done by function `updateScore()`.

The stop condition may influence case score.

– Condition 1: All perceptions of agent context have been found in a path, but there is no equality between case and situation context (case has more perceptions than context or there is no time to continue the search). No bonus is given to the score of this case. $bonus_k = \alpha = 0$
– Condition 2: Actual node is a leaf, so we have perfectly identified a case. A bonus is added to the case score. $bonus_k = \alpha$ where $\alpha \geq 0$ is a rewarding parameter, empirically defined.
– Condition 3: One can not find edges leaving the node with the current value. In this case $bonus_k = \beta * n$, where $\beta \leq 0$ is a penalty called correction rate and n is the number of remaining perceptions of the current context.

Algorithm 1: Perceptions tree search algorithm: treeSearch(context)

```
begin
    if (context is empty) then
        return True // Stop condition 1
    end
    nextNodes=[ ] //vector of nodes to visit
    foreach (perception in context) do
        if (node predicat and perception can be unified) then
            nextNodes ⟵ findNextNodes(perception.value)
            if (nextNodes.size()==0) then
                //Stop condition 3
                updateScore(score)
                return False
            end
            else
                foreach (node in nextNodes) do
                    context → delete(perception)
                    if (treeSearch(context)) then
                        //recursive call
                        updateScore(score)
                        //Stop condition 2
                    end
                end
            end
        end
    end
    //Every node has been visited
    return True
end
```

Algorithm 2: following nodes search algorithm: findNextNodes(value)

```
begin
    nexts=[ ] //vector of following nodes
    foreach (edge leaving this node) do
        if (node.value==value) then
            nexts→add(node)
        end
    end
    return nexts
end
```

An score equality between cases can occur at the end of search, a case between the possible ones is randomly selected. The probability for a case to be selected depends of the number of selection of this case. Only times when the stop condition *2* is reached increases the probability for the case to be selected.

5 Example of results

We introduce in this part a first result from our simulator. An important aspect of CoPeFoot is the possibily to replay a situation, in order to show the important points of the simulated situation, this can be useful for psychologists experience or for training. We track entities position, the following figure shows trajectories of players and ball. We show, on figure 6, a 2D trace from our restitution software.

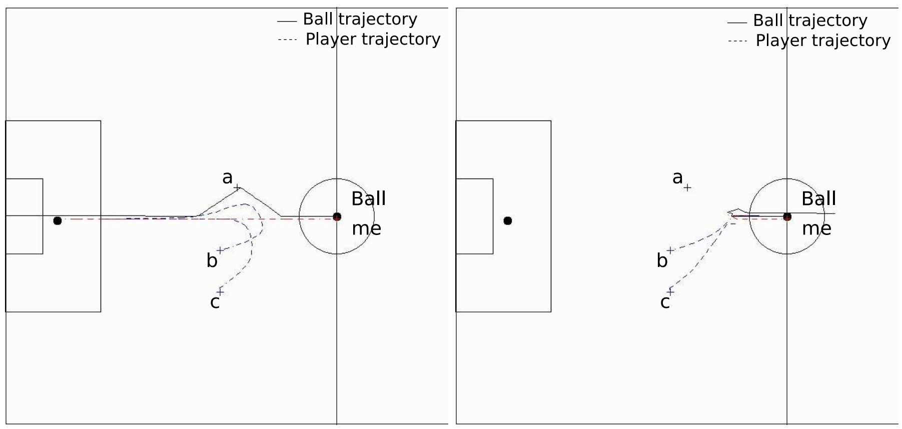

Fig. 6. Examples of agent trajectories

The situation is the one introduced at the beginning of this paper. Players "me" and "a" have to collaborate to score. The first picture illustrates the decision-making and the trajectory of player "me" who has the ball at the beginning. Its decision-making is based on the four contexts introduced earlier. When opponents are too close, it decides to pass the ball to player "a". In the second figure we have deleted the team context, player "me" does not know that it can pass the ball to its partner, because it does not know who is its partner or opponent. The ball is lost and opponents go to the other goal and score. The aim of this example is to show up the possibility of easily degrade agent contexts to experiment influence of different contexts in decision-making.

Thanks to context use, we are able to keep relevant perceptions. We have developped a restitution software in 2D and 3D. The first one allows to keep a trace of entities trajectory. The second one is used to replay a situation. We can show up perceptions as shown on figure 7. This part of software can be either for

Fig. 7. Example of 3D restitution

experimentations or for training, but it can be used to build agent experience. Expert plays a situation and we can show him the result. He can show the perceptions he used to take a decision. According to this result, perceptions relevance can be estimated.

6 Conclusion

We have introduced in this document, that context notion can be seen as a perception filter and as a knowledge representation for virtual reality simulation. The paradigm of case based reasoning can be a good way to model agent behaviour. We argue that context in association with case-based reasoning can provide important elements to set up a virtual environment for training. The first point is the behaviour credibility of agents evolving in our simulator, thanks to simplified analogies with human mechanisms this credibility can be enhanced. The other aspect is to make the agent decision-making process as explicit as possible to explain it to a user. This is possible thanks to context which allows to have a semantic on agent perceptions, the case representation as a path in the perception tree allows to explain choices during the resolution.

Our case base representation, thanks to tree, permits a better visibility for a domain expert. This can ease its integrity verification, and it allows to let an expert set up the base and so agent behaviour. Expert plays in simulator and its action and contexts are stored in the tree. At the end of the demonstration, we can show him the new tree and he can adjust weight of all perceptions for each new case. This work is done in collaboration with sport psychologists that help us to set up some tests in order to validate our approach in the next months.

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Situational interests and meaning negotiation process

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Abstract - In different situations of life, both common and institutional, it happens that some people negotiate the meaning of terms and sentences. The research investigates the meaning negotiation processes. In particular, negotiation processes produced by agents who are collaborative (contract), but then they become conflicting (controversy). The kind of approach that we believe plausible to the problem of meaning, in meaning negotiation processes, turns on the idea that to determine which is the *plausible* meaning we must have recourse to a decision. In our view, this decision is founded on what the agents take to be their interests

Keywords: determining of meaning; individual interest; decision; social network; negotiation process of interests.

1 Introduction

The problem. In different situations of life, both common and institutional, it happens that some people negotiate the meaning of terms and sentences. This negotiation occurs both in situations where it is necessary to resolve a controversy (e.g. in law courts) and also when there is no strong reason or apparent motivation present (e.g. in pub). But if the meaning is conventional, then why do we negotiate it? Is it not enough to refer to the conventions?

Domain of research. The research investigates the meaning negotiation processes. In particular, negotiation processes produced by agents who are collaborative (contract), but then they become conflicting (controversy).

The interdisciplinary plane of research is composed from several disciplines: sociology of knowledge, philosophy of language and knowledge, logic, theory of decisions. The case-study concerns contracts of employment, in particular ambiguous clauses.

The kind of approach. The problem of meaning, namely the problem of determining the 'correct' meaning of a term or sentence, is a key topic in the study of language and linguistic processes. The kind of approach that we believe plausible to the problem of meaning, in meaning negotiation processes, turns on the idea that to determine which is the *plausible* meaning we must have recourse to a decision. In our view, this decision is founded on what the agents take to be their interests.

Hypothesis of research. The research is based on the hypothesis that situational interests of agents drive meaning negotiation process of ambiguous clauses. In general ordinary tools are not powerful enough to determine a specific interpretation, in particular where the 'correct' interpretation is relevant the parties have recourse to a decision based on their situational interest.

The paper is structured as follows. In *Ordinary tools are not powerful enough*, we discuss how in some cases dictionary, encyclopaedia, context of use and knowledge domain are not powerful enough in determining of meaning of an ambiguous clause. In *Case-study: an ambiguous clause*, a case of linguistic controversy is presented, where an insurance company and a new graduate are involved. In *Interest and decision*, the hypothesis of research is specified and motivated. In *Interest, preference and choice*, the individual process of choice of meaning is described using some basic notions from decision theory. In *How the interests are socially connected to meaning*, we sketch out negotiation process and determining of meaning with respect to social interaction, on the basis of interests' agents. We follow the main intuitions of *Actor Network Theory*.

We introduce a definition work for "meaning negotiation process". It is the interactive process between two or more agents to set meaning of a term or sentence, where the agents' interpretations are conflicting or partially discordant. The main characterizes of the process are: agents must consider their own interpretations relevant for any their activity, that is, the interpretations must represent interests of involved agents. The activity must be mutual, namely it must involve the contractual agents when the semantic agreement is reached. In negotiation process the semantic equilibrium is reached giving or taking resources for and from other parties. The meaning negotiation process is a social process[1].

2 Ordinary Tools are not Powerful Enough

In this paragraph we discuss how in some cases dictionary, context of use, and knowledge domain are not powerful enough in determining of meaning of ambiguous sentences in a contract.

We consider the expression (2) "cessation of the absence", which in Italian can have different interpretations, these interpretations arise by composition of meanings of the single terms[2]. We find interpretations of single terms in the dictionaries. In essence dictionaries contain some axioms that code linguistic and factual knowledge[3].

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[1] Our definition work is compatible with definition of the *semantic negotiation* proposed by Bouquet and Warglien: "*semantic negotiation*, namely the problem of reaching an agreement on the meaning of an expression when (i) an agreement is valuable for all agents, but (ii) agents have conflicting preferences over which solution should be selected, so that every agreement implies that at least someone has to concede to some extent to other agent" [5, p. 2].

[2] In according to the *principle of composition* [19, pp. 21-26; 3].

[3] Dictionary and encyclopedia provide lexical knowledge and certain axioms that manage the meanings of the terms and predicates. Note that a clear distinction between dictionary and encyclopaedia there is not [11; 17]. Intuitively we consider that a dictionary contains only "succinct properties of terms", on the other hand an encyclopaedia contains "complex descriptions" [11, p.197].

For example, for the word "cessation" in the Demauro dictionary, there are two interpretations:

a) *it is putting on the end*, *it is having end;*

b) *interruption*, *suspension*.

For the word "absence" there is four interpretations:

c) *to be far*: absence to the work;

d) *lack*: lack of air, lack of light, lack of gravity;

e) *situation of uncertainty of life of a person for at least two years subject to the decision of judge*: declaration of absence;

f) *temporary loss of consciousness*: in particular to cause of epilepsy, hysteria, intoxication's forms.

In natural language (e.g. Italian), we can compose complex expressions using the interpretations of "cessation" and "absence", for example: (3) "*temporary loss of consciousness is having end*" or (4) "*interruption of situation of uncertainty of life*". As well, with respect to the specific case we can compose: (5) "*to be far to the work is having end*". All these expressions have sense in Italian, but not all are adequate for the context of contracts of employment.

The context of use rules out some interpretations. For example the interpretation (3) could be adequate in a hospital, but not adequate in a law court, instead (4) could be adequate for a judicial examination of a criminal court, but not adequate in a contract of employment. In the context of contracts of employment not all interpretations of (2), accepted in Italian, are plausible. However (5) can be an adequate interpretation in the context of contracts of employment, but in our case it does not resolve the ambiguity of the clause[4].

Moreover, another level of interpretation is possible because the language of contracts is managed by specific rules and specific knowledge that determine which can be the acceptable interpretations of a sentence in a contract of employment[5]. This knowledge belongs to knowledge domain and background knowledge of agents. In essence, to determine the meaning of (2) "cessation of the absence" to the natural language specific axioms have to be added. These axioms can regard several levels of encoding of the knowledge of contract's world, for instance: the Civil Code, the Labour Law, lines of tendency of main law courts (e.g. Milano with respect to financial issues), etc.

For example, we report the main criteria of disambiguation of contract's ambiguous clauses from Italian Civil Code and court's practices:

1) *literal meaning* (art. 12 Pre-Laws of Civil Code);

2) *combined interpretation of clauses* (art. 1363 C.C.);

[4] In according to Bianchi, there are two notions of context in philosophy of language: *semantic* and *pragmatic*. The semantic context determines some variables, in particular it fixes identity of speaker and interlocutors, time, place of uttering and so on. The pragmatic context is composed of a network of intentions, activities of interlocutors, and it contributes to determine their communicative intentions [2, p. 24].

[5] In according to Wittgenstein [31], we could say that in a life form (contractual activity) each linguistic game has specific rules or uses.

3) *exegesis of common intentions of parties* (art 1362 C.C.);
3) *previous verdicts* (praxis);
4) *doctrinal exegesis* – from University.

This kind of specific knowledge belongs to knowledge domain. It provides a further level of encoding. Using knowledge domain the agents reduce the possible interpretations, but it can happen that it is not yet possible to determine actually which the plausible meaning of a clause is. A linguistic space could remain yet indeterminate. In our case the four criteria do not resolve the ambiguity. Incidentally, if the tools of interpretation left an opened semantic space, then an agent could sustain the meaning connected to his own interest and contemporaneously does not lie.

In summarize, in a linguistic controversy with respect to an ambiguous clause agents (or their lawyers) use dictionary, context of use, knowledge domain. In our case, they were not able to determine the plausible meaning of the clause and the case is in law court.

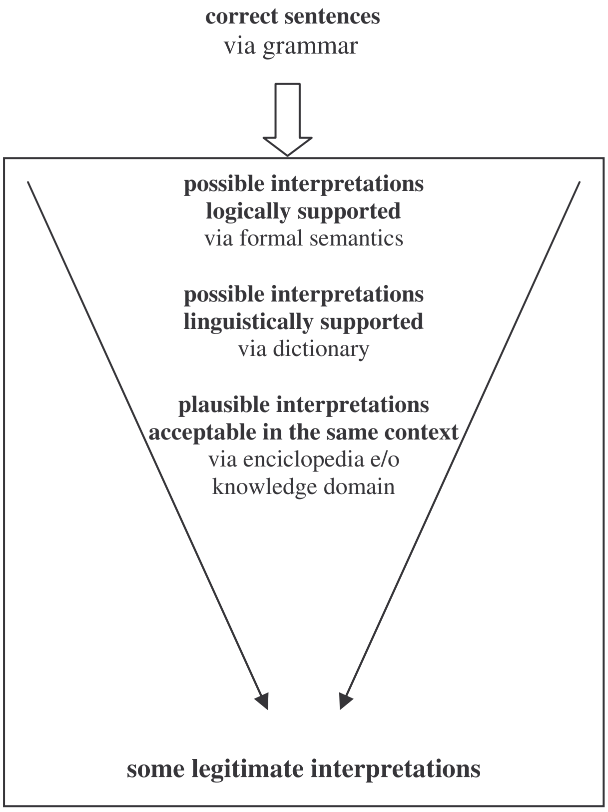

Fig. 1. **Cone of semantics 1**. Process of reducing of meaning via ordinary tools[6].

[6] For completeness in fig. we have added also the grammar level. In general, applying grammar rules (e.g. from Italian grammar) we can build correct sentences in Italian. In this

Note that the 'cone of semantics' begin with the level of possible formal interpretations, via formal semantic[7]. In according to Diego Marconi, we consider that a modelling semantic without postulates of meaning (see Carnap) does not provide the meaning of a sentence, because semantic values of descriptive constants are left underdetermined (excepting for the logic type) [18, p. 128 – *translation is mine*]. Postulates of meaning are linguistic stipulations (e.g. "bachelors are not married"), they are coded in dictionaries and encyclopaedias. Marconi continues, we have seen that neither a modelling semantic with postulates of meaning makes available the meaning of a sentence, because it is not powerful enough to provide all content of speaker's competence: postulates of meaning certainly reduce possible interpretations, but they do not give a unique interpretation. Therefore the modelling semantics do not answer indeed to the question: "what does the sentence mean? Neither if we consider it together with a collecting of postulates. In this case, it is not a theory of meaning for natural language" [18, p. 128 – *translation is mine*].

3 The Case-study: an Ambiguous Clause

The case-study concerns contracts of employment, in particular ambiguous clauses. We report a case of a controversy where an insurance company and a new graduate are involved. The controversy was born with respect to the interpretation of a clause that contains an ambiguous expression. The clause is as follows (1):

"In particular it is understood that the relation of work, which was established with you, will resolve into the *cessation of the absence* of Miss Maria Rossi, and however not beyond 23 December 2005"[8].

This clause governed the engagement and employment time of the new-graduate by the insurance company, with respect to maternity leave of M.R. During the time of substitution, M.R. resigns and the employer asks the new graduate to cease employment, because the absence of M.R. is ceased. The new-graduate argues that the clause's meaning refers to the pushed forward return of the M.R. after maternity and not to her absence due to cause of demission. The new-graduate sustains that they have to refer to *term* 23 December and not to the *condition* represented by (2) "cessation of the absence", that in new-graduate's opinion is not happened[9].

Even with the aid of tools as dictionaries, encyclopaedias, Civil Code, Labour Law[10], they were not able to determine the meaning of the clause. Note that in the

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sense the grammar provides the structure in which dictionary, encyclopaedia and knowledge domain can work.

[7] Here, we consider the formal semantics in the terms of Tarski.

[8] "In particolare resta inteso che il rapporto di lavoro con lei instaurato si risolverà alla *cessazione dell'assenza* della signora Maria Rossi e comunque non oltre il 23 dicembre 2005".

[9] The clause shows a semantic ambiguity. In the current research also we consider clauses where there is syntactic ambiguity.

[10] In Italy, the Labour Law is a collection of laws. The book that collects the collection (partially) depends on editorial decision of editors. Instead, the Parliament fixes precisely the Civil Code both the collection of laws – as in the case of Labour Law - and also the book.

real situation lawyers treat the case for their clients. Of course they could lie, but it is nevertheless true that the judge will use the same tools to determine the meaning. In a knowledge theory view lawyers and judge share similar background knowledge, and they are able to use the same tools.

4 Interests and Decision

We ask ourselves, how is it possible to discern which is the plausible meaning? Or better, how do the agents determine the meaning in this situation? Is it always possible to clarify all linguistic rules and extra-linguistic rules related to the particular context that we permit us to pick out the plausible meaning? In our view in some cases to discern which is the plausible meaning is a problem of decision. In particular, each party chooses a meaning, which will satisfy her/his own interests.

The main thesis of the research is that in meaning negotiation processes can exist a relation between possible logical models of sentences of a text (contract) and the agent's interests (or better what they believe to be their interests). Considering that a sentence that has an interpretation - on which agreement is founded - can be interpreted in other ways semantically sound, also radically different, we think that the relation between linguistic formulation of the contract and its possible logical models (semantic) can depend on extra-semantic interests of involved parts (e.g. economic, social, moral, ideological, etc.)[11].

The determination of meaning of an ambiguous clause depends on the linguistic formulation, that pattern a semantic space, and certain axioms (different levels of knowledge). Usually they provide the conditions to determine a plausible meaning, but sometimes they do not work and a choice is necessary. In our view the choice is connected to the interests and the interests can be described with relations of preferences. In the paragraph *Interest, preference and choice*, we shall describe the process of choice of meaning using agent's preferences. In *How interests are socially connected to meaning*, we shall describe the social process of determination of meaning.

In synthesis, the contribution of the research consists in sketching out the modalities of determination of the sentences' meaning in natural language highlighting the relation between the interpretation of sentences, their formulation, the interests of agents and their to come to a decision on the meaning.

5 Interest, Preference and Choice

In this paragraph we describe the process of choice of meaning using some basic notions from *Decision theory*, i.e. relation of preference, completeness and a rule of choice [see 10, 16, 23]. First we summarize the structure of the situation up to this point, and then we try to throw light on its connection with the basic notions from

[11] Note that often linguistic formulation of sentences of a contract is obtained by negotiation between the parties, but it is not our case.

Decision theory. In the first phase of process, we have a correct sentence of natural language (by grammar and vocabulary). It can have some possible meanings, they are compatible with the structure's sentence. They are not contradictory to knowledge from dictionary and encyclopaedia (possible meanings).

In second phase, we have some plausible meanings (selected from possible meanings), these are not contradictory to knowledge domain (e.g. Civil Code), and they are compatible with the context. Nevertheless in our case, we have yet a semantic space (set of plausible meanings). At this point the two agents choose an option that guarantees their own interests. In brief, if the meaning is *A*, then the contract will solve. If the meaning is *B*, then the relation of work will continue.

Before to describe the process of individual choice of meaning, we draw the two meanings. The interpretation *A* can be expressed as follows: the worker during maternity leave belongs to the organization of the company. But since *de facto* during this period she resigned, then she no longer belongs to the company. If she currently does not belong, then her absence is not absence from the company (the condition of absence is connected to the condition of belonging, hence if there is not belonging there is not the condition of absence). It follows from this that the absence is ceased, "(*c*) the absence to the work (*a*) is having end" (interpretations *c* and *a* from Demauro dictionary). In brief, if the meaning of (2) is *A*, then the contract will resolve.

The interpretation *B* can be expressed as follows: the worker during maternity leave can not carry out her task in the company. The company takes on a new graduate to carry out them, since the absence of worker *de facto* stops their carrying out. The accent is put on the goal of worker and not on her belonging to the company. Hence, if the goals of the worker must be yet performed in the company, then the absence of worker (of her goals) is not ceased. Therefore there was not "(*b*) the suspension of (d) lack of the goals" (interpretations *b* and *c* form Demauro dictionary). In brief, if the meaning of (2) is *B*, then the contract will continue until 23 December.

The interests of the agents can be summarized as follows. We know that the company aims at a reduction of staff, because its economic situation is not very good. Also, we assume that the company wants to avoid that *Ag2* could contest the contract. Hence the interests of *Ag1* are as follows: "*Ag1 wants to save money. He does not need a worker. He wants to avoid that Ag2 could contest a legal case*". In the other case we report the real *Ag2'* interests, because we interviewed him. The interests of *Ag2* are as follows: "*Ag2 wants to maintain position in the company. He wants to receive the salary. He wants to avoid a legal case*".

5.1 Relation of Preference

In *Decision theory* three comparative notions are commonly used to express the relations of preference: "better than" ("$>$"), "equal in value to" ("$\equiv$"), and "at least as good as" ("$\geq$"). The relation "$>$" is said to represent *preference* or *strong preference*. This notation, that is essential part of the formal language of preference logic, can be used to describe the relation between the preferences of the meanings.

However, in our case we will only use "better than" and converse “worse than”, they are powerful enough to describe the current situation[12].

The preferences of the agents with respect to the meanings can be formally represented in the language of preferences as follows:

1) *Ag1*: the meaning *A* is better than meaning *B*;

2) *Ag1*: the meaning *B* is worse than meaning *A*;

3) *Ag2*: the meaning *B* is better than meaning *A*;

4) *Ag2*: the meaning *A* is worse than meaning *B*.

This pattern shows that *Ag1* prefers in strict sense the meaning *A* rather than the meaning *B*. On the other hand, it shows that agent *Ag2* prefers in strict sense the meaning *B* rather than the meaning *A*.

In decision theory the property of *completeness* is an essential notion. “The formal property of completeness (also called connectedness) is defined for a relation *and* its domain. The relation ≥ is complete if and only if for any elements A and B of its domain, either A≥B or B≥A” [23, p.18; see 16]. In our case, when the agents choose one plausible meaning (we could call it “preferred”) from a set of plausible meanings {*A*, *B*}, the options are both exhaustive of domain and ordered (complete). Ordinary tools and knowledge domain already worked closing the possible options. Nevertheless it remains a reduced semantic space in which the options are related. Hence, the formal property of completeness is respected.

In essence in the current situation, we have two possible courses of action in a closed and ordered set of options. The options are exclusive that is it is not possible to fulfil both of them. We have some essential elements to describe the process of choice of meaning. An agent will choose the option that respect his preferences (complete) and thus satisfy his interests (connected to his preference). In this case the rule of choice is as follows: an option is the best if and only if it is better than all other options. If there is a uniquely best alternative, then choose it (see Hansson 1994). In this case *Ag1* chooses the meaning *A*, and *Ag2* chooses the meaning *B* both of them in accordance with the rule of choice.

Ag1 chooses the meaning *A*, because satisfies his situational interests. On the other hand, *Ag1* does not choose the meaning *B*, because does not satisfy his interests. *Ag2* chooses the meaning *B*, because satisfies his situational interests. On the other hand, *Ag2* does not choose the meaning *A*, because does not satisfy his interests. The process of individual choice does not exhaust determining of meaning, social dimension is essential as we shall see in the next paragraph.

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[12] Note that, in common sense we use "better than" in case that at least one of the options is acceptable and "worse than" when both are not acceptable [23]. Here, we consider "better than" and "worse than" to be symmetric.

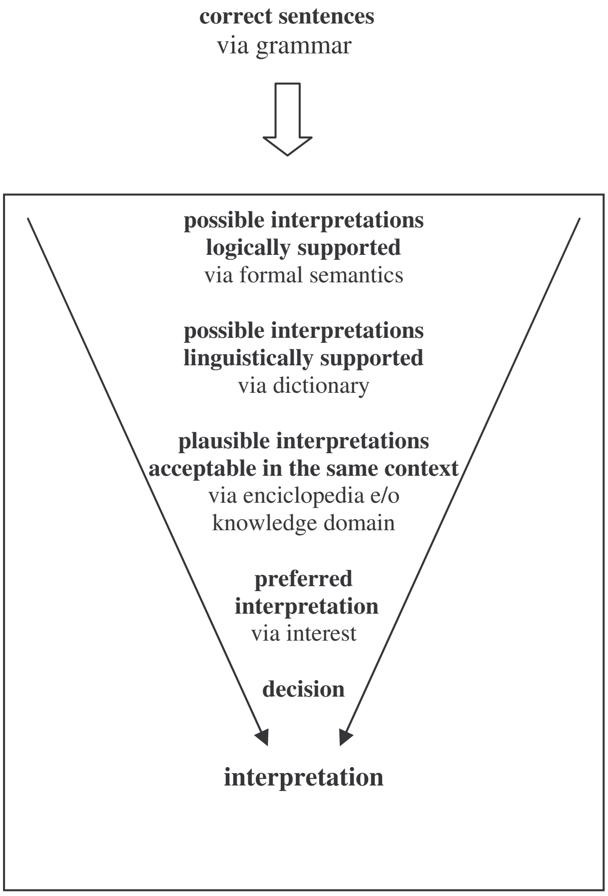

Fig. 2. Cone of semantics 2. The process of reducing of interpretations. The last step is a decision.

6 How the Interests are Socially Connected to Meaning

Intuitively the interests of agents stabilize the meaning in cooperative cases. A good illustration of this is the communication, where the interest is shared. On the other hand, in conflicting cases they drive the meaning, the topics of current research is a case in point. In any case the interests socially work.

We believe it is plausible that the semantic agreement on ambiguous sentences of contract is produced in the negotiation process between the agents with respect to their interests. In this sense, we think the meaning as an epiphenomenon of the underlying negotiation process of interests.

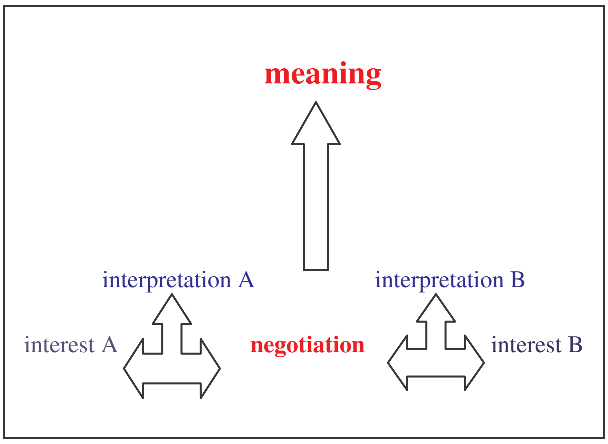

Fig. 3. The meaning as an epiphenomenon

We believe that to understand some mechanisms that govern meaning negotiation process, it is useful to observe the underlying social dynamics. At this goal, we follow the direction showed by Actor Network Theory (ANT). We use the notion of social network.

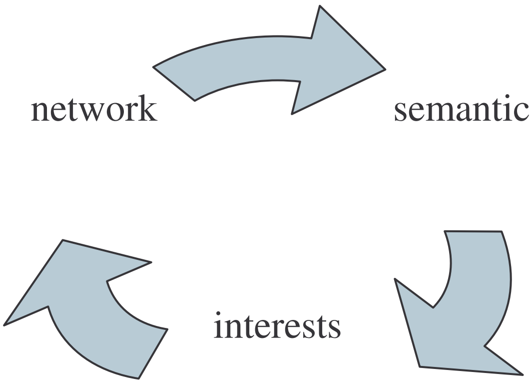

Fig. 4. The circular relation between interest, network and meaning.

What is a network? In according to Michel Callon, a network is composed of hybrids intermediaries: texts, technical objects, capacity, money, etc. [7]. A network is built of relations between elements of different nature: humans and not humans. In our case not human actors can be Civil Code, previous verdicts, references, quotations, as well capacity of argumentation or financial resources, etc. Human actors are the two agents and/or their lawyers and the judge. In the ANT approach, production of knowledge (also scientific) is viewed as an effect of networks composed of these heterogeneous materials. In particular, the meaning of a sentence is stable if it is connected to more possible other elements of network [21].

How are elements connected? A key concept in ANT approach is the *enrolment* [22]. Enrolment means that an agent uses some elements in his favour, that is they work for him and become actors of network. Also, it means that an agent attempts to convince other agents to share his position. In Bruno Latour's view: "the appeal to higher and more numerous allies is often called the argument of authority" [21, p.41 – *translation is mine*]. In the court high allies are the judge, Civil Code, previous verdicts, legal opinions of famous lawyers, as well the current ideologies as politically correct, etc. The connection of these actors increases the degree of "irreversibility" (of network), thus it is not possible to return back to the initial situation on which there were different translations all on the same plan [7, p.150]. In ANT translation means translation of interests between actors that are allying in the network.

How does network work? In our case, ordinary tools (D, E) and knowledge domain (e.g. criteria from Civil Code) didn't work. The agents chose a meaning. The two lawyers attempt to convince the judge. They can argue in several ways. For example, the lawyer *L1* shows an old verdict - *praxis*. It refers to a different case, but the lawyer argues that under certain aspects it is compatible with current case (e.g. an analogous case where the worker is died and the judge resolved the contract arguing that it was common intention of parts – art. 1362 c.c. - to constrain the relation of employment to the physical presence of worker). Or, *L1* can show a foul proof where the formulation is clearer, or he can bring a witness, etc. Yet, he can use a current ideology (e.g. politically correct) to modernize an old verdict (in Italian industrial tribunal there is the "principle of *favor*", that is the tendency to protect the weaker part). These argumentations and strategies, which do not belong in *strictu sensu* to knowledge domain (at least of institutional kind), are common in lawyers' practice[13]. In according to Latour [21], in a controversy, if the ambiguous meaning of a sentence is connected to other more sure sentences, then it will become less ambiguous[14]. In this case if the lawyer is able to argue the compatibility between the two cases (demission and death of worker), then old verdict will provide credibility to his interpretation of clause. The old verdict becomes a high allied. Also, the old verdict activates another higher allied: a criterion of Civil Code. Incidentally, the Civil Code works as a "black box". The concept of black box is similar to "paradigm", that is accepted as a fact. However, if the judge accepts the argumentation, then also he will be enrolled and become a high ally with *Ag1*/*L1* in the local network. Now the interpretation *A* has many allies: old verdict, criteria from Civil Code and Judge[15].

How does the judge's interest work? The judge accepts the argumentation (compatibility), because it is pertinent to his interests in the Justice (3rd criterion in Civil Code: *previous verdict*). The judge decides in favour of the interpretation A, since it satisfies his own interest. In this way the judge simultaneously guarantees both his own interest and of a party. A translation of interests happened. Note that the individual process of choice of judge can be described using relations of preference[16].

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13 We have acquired legal information from some labour lawyers.

14 For an interesting analysis of rhetoric in scientific literature see [21, pp. 27-78].

15 The concept of ally is not contradictory with the notion of resource proposed by Conte and Castelfranchi: 'a resource is every entity involved in an action and useful to it, except the agent himself' [8, p. 244 – *translation is mine*).

16 The notion of translation of interest is compatible with the conception of adoption of interest proposed by Conte and Castelfranchi: 'If an agent believes that the adoption of a goal

Finally, we describe the strategy of translation of interests in the situation. In Latour view "the easier way to find people that believe our sentence (…) is to define the object in a way that satisfies their explicit interests" [21, p. 145 – *translation in mine*]. In our case, *L1* attempts to satisfy the judge's interest in the Justice, showing a verdict which is compatible with the case and actives a criterion of the Code. Latour continues, why would people believe our solution? "The reason is only one: *their usual way is blocked* [21, p. 148 – *translation in mine*]. In our case the usual way is blocked because the ordinary tools did not work in determining of meaning of the clause. The last step is to propose "a short cut. It is a tempting alternative, but three conditions must be satisfied: the usual way is clearly blocked; the new way is well sketched out; the deviation appears short" [21, p. 149 – *translation is mine*]. The new way has been short: a previous verdict has been showed and the deviation (argumentation of compatibility) has been much clear: it pointed directly at Civil Code.

In synthesis we believe plausible that in this way the meaning of (2) can enter in the language of contracts and this fact is documented by a judge. In according to Latour [21] we can say the sentence (2) went from artefact to fact, and the meaning became a reference (paradigm). In according to Wittgenstein [31] we can say that we fixed a correct interpretation/use of the sentence (2) (in a linguistic game) and it will work as a reference ("rule-following") in the world of contracts (life forms)[17].

7 Summarize and next development

The research consists in sketching out the modalities of determination of the sentences' meaning in natural language highlighting the relation between the interpretation of sentences, their formulation, the interests of agents and their to come to a decision on the meaning.

We have seen that the linguistic formulation of a clause permits some interpretations, also totally different between them. We have seen that the context of use of an expression rules out some interpretations between possible ones with respect to certain situation. We have seen how the agent's interests drive the choice of a between a set of plausible interpretations in the context of employment's contracts. Finally, we have seen how the meaning of an ambiguous clause is fixed in the social interaction and how is available for next linguistic interaction.

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of another agent is a mean for an its goal, then it will adopt such goal' [8, p. 244 – *translation is mine*).

[17] Elements of network and their relations structured on the basis of agent's interests provide the conditions to reify a part of language. This reified part is available in the (next) network and work as a fact. This dialectic seems to be moving in opposite direction to the direction proposed by Peter L. Berger and Thomas Luckmann, where the use of language reifies social reality [2].

7.1 Next development

In the next step of the research we consider strategic dimension. We suppose that the director of staff is experienced. He knows both interpretation A and B, instead the new-graduate knows only the meaning B. "He knows both meaning A and B" means that the director knows the possible situations, that is the possible conditions that make true both the interpretations A and B of sentence (2). For example, the director could know that some workers during the maternity leave resign. He can use this knowledge in his favour when he writes the text of contract (linguistic formulation). We could say that the director has, at least, two representations of meaning of (2) on the basis of his knowledge. The new-graduate has only one representation. There is an epistemic asymmetry between the representations of agents. To capture this asymmetry we shall use some notions from knowledge representation. In particular from Theory of contexts (*Multi-context system - SMC*) by Fausto Giunchiglia [13] and Paolo Bouquet [4].

The main intuition of Giunchiglia is that many cognitive processes are local, that is they imply only a subset of information that an agent has. The context is viewed as a subset of knowledge-base and of resources that an agent uses in a reasoning. A context is defined as follows: "a context is a theory of the world which encodes an individual's perspective about it. It is partial theory as the individual's description of the world is given by the set of all contexts. It is an approximate theory […] as we never describe the world completely" [13]. Also we consider the cognitive dimension of context of Bouquet [4] in accordance with Giunchiglia: a context is viewed as a subset of cognitive state of an individual that on the basis of some assumptions ("environment" of process) that are used by an agent in a circumstance to reason on a problem [4, p.172 – *translation is mine*][18]. In Giunchiglia [13] it is presented as a truth theory which agents use in reasoning. Giunchiglia puts the accent on partiality and approximation of theory. Also, Giunchiglia does not consider in *strictu sensu* the assumptions and their structure, but he considers the fact that different sets of assumptions produce different representations (partial and approximate) of a certain state of affairs.

The notions of locality and compatibility are very important in this conception. In [15] Giunchiglia and Ghidini have defined the principles of locality and compatibility. The theory SMC is provided of a powerful logical apparatus. It is compatible with local-model semantic [14, 12].

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[18] Note that this cognitive characterization of context is in accordance with Sperber and Wilson [27, p.15-16].

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Modeling Contexts of Knowledge Sharing in an Online Community for Oral Medicine*

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Abstract. To support knowledge sharing between practitioners of oral medicine throughout Sweden, the SOMWeb system for community collaboration has been constructed. In the system, community data and medical knowledge are represented using Semantic Web technologies. One function of the system is to support the discussion of difficult and interesting cases at a monthly telephone conference. From our observations of these meetings, the users' responses to a questionnaire, and discussions with users, we find that many of the improvements that can be made to encourage further use of the system relate to adding the representation of context. Some initial thoughts on what would be relevant to represent in relation to context are given, such as the experience of the practitioner, the reason for adding a case to the system, and the current activity of the user. The long-term aims of this work is to identify aspects of context relevant to online communities of practice in healthcare, and to investigate how these contexts can be modeled using Semantic Web technologies.

1 Introduction

Many hold that health care should be evidence-based, meaning that care should be based on identifying, validating, and using the latest research results as a basis for clinical decisions [1]. To practice evidence-based medicine (EBM) entails integrating the expertise of the individual clinician with the best medical evidence obtainable from different knowledge sources. One part in promoting EBM can be supporting the communities of practice that are formed by practitioners of a medical domain. A community of practice [2] is a group of people "who share a concern or a passion for something they do and learn how to do it better as they interact regularly" [3]. A case of special interest is the possibility of using the Internet to support virtual communities of practice, where members are geographically dispersed and where face to face meetings are rare. A virtual community of practice has at its disposal both traditional media, such as

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telephone, telephone conferences, and fax machines, as well as more recent technological tools, such as e-mail, common databases, websites, and online meeting spaces [4].

Oral medicine is a sub-discipline of dentistry concerned with diseases related to the oral and paraoral structures. This includes the principles of medicine related to the mouth, as well as diseases specific to the orofacial tissues and oral manifestations of systemic diseases. The specialty is quite small, meaning that cooperation between geographically distributed clinics is beneficial for collecting diverse and numerous cases for analysis, and also for providing a means for consultation and learning for a broader audience. The Swedish Oral Medicine Network (SOMNet) is a collaboration between clinicians in oral medicine, located at clinics throughout Sweden. Together with computer science departments at Chalmers University of Technology and the University of Skövde, the Swedish Oral Medicine Web (SOMWeb) system for community collaboration has been developed, with a basis on Semantic Web technologies such as the Web Ontology Language (OWL) and the Resource Description Framework (RDF). Currently, a major usage of the system is supporting the monthly telephone conferences of the group, centered around the discussion of cases. Through these telephone conferences, the terminology used at various institutions becomes more harmonized, treatment strategies can be assessed, and the individual clinician can be advised on difficult cases, among other things.

We have recently observed the system's use at several meetings, in addition to studying the users' usage and opinions through a questionnaire. Through our observations and the questionnaire, we see that several of the improvements that can be made relate to context. In a knowledge intensive discipline, knowledge sharing is a large part of a community's interaction. In health care, this can include sharing cases, research articles, or advice. These are often found and contributed within a context, and we believe that computer mediated knowledge sharing can be facilitated by including a dimension of context. This leads us to believe that users of our system can benefit from modeling the contexts of use and the contexts of information in the system, and this paper represents some initial thoughts in this direction. The long-term aims of this work is to identify aspects of context relevant to online communities of practice in healthcare, and to investigate how these contexts can be modeled using Semantic Web technologies.

We begin, in Sec. 2, by describing aspects of knowledge sharing. In Sec. 3, we provide some related work in the area of context, in general and in the areas of ontologies, health care applications, computer supported collaborative work (CSCW), and online interactions. We then describe the SOMWeb system in Sec. 4 – its functionality and the ontologies used to represent community data and knowledge in oral medicine – followed in Sec. 5 by our analysis of the use of SOMWeb through observations and questionnaires. In Sec. 6 we give initial thoughts of what contexts are relevant to model, as well as how these should be represented in our system. Finally, we give a short summary and discuss future work in Sec. 7.

2 Knowledge Sharing and Formalizing Knowledge

One of the activities of a community of practice is learning from other members, which can happen when members of the community share their experience and knowledge. Polayni [5] put forth that a person can possess both explicit and tacit knowledge, where explicit knowledge is that which can be transmitted through a systemic language, while tacit knowledge is personal, context specific, and thus hard to formalize and communicate. Knowledge that is explicit for one group or person can be tacit for another.

This distinction of tacit and explicit knowledge was popularized in knowledge management circles by Nonaka and Takeuchi [6], who also introduced the concept of knowledge conversion in relation to this distinction. The processes of knowledge conversion – socialization, externalization, internalization, and combination – relate to how knowledge moves between forms of tacit to tacit, tacit to explicit, explicit to tacit, and explicit to explicit, within and between people.

In using technological means to support knowledge sharing, an element of knowledge formalization is often involved. Formalization can be carried out to different degrees, e.g., it can involve subsets of the collected information and the formalization can be more or less rigorous. This formalization is of use, in among other things, when later browsing and retrieving information and if one wants to use collected data to find new relations. Such relations could be between e.g., a disease and a certain lifestyle, and methods for finding them can be e.g., data mining or user-guided visualizations.

However, making explicit and formalizing knowledge is often difficult for the end-user of a system. Shipman and Marshall [7] discuss such difficulties, drawing on examples from areas of hypermedia, argumentation and design rationale, knowledge-based systems, and groupware systems. Reasons proposed for these difficulties are cognitive overload, tacit knowledge, negative effects of prematurely imposing structure, and that different formal structures are needed to support different situations requiring different user support. Approaches to minimize the problems of formalisms are also proposed:

- Work with users to reach a shared understanding of the use situation and what representations suits it best.
- Based on trade-offs introduced by additional formalization, identify what other services or user benefits the computer can provide.
- Expect, allow, and support reconceptualization and incremental formalization in longer tasks.
- Provide facilities that use undeclared, automatically recognized structures to support common user activities.
- Provide training and facilitation to help users work effectively with embedded formalisms.

In dealing with explicit medical knowledge, an emphasis on context (temporal, spatial, cultural, and social) is needed [8], and we believe that representing context can be used to alleviate some of the difficulties of formalization for knowledge sharing.

3 Context

Context has been an area of study of various partially overlapping subjects, such as linguistics, philosophy, psychology, and computer science. There is not one way of defining context, and a researcher's perspective on context depends his or her background. A suitable definition of context for this work has not yet been decided upon, but we here give some different ways of looking at context. In the following subsections we bring up proposed uses of context in fields relevant to our work: ontologies, health care, CSCW, and online interactions.

A commonly used definition is that of Brézillon [9], who defines context as "what constrains a problem solving without intervening in it explicitly", stating that this applies to the domain of cooperative problem solving by a human and a machine. Pomerol and Brézillon [10] discuss three types of context: proceduralized context, contextual knowledge, and external knowledge. Proceduralized context is directly but tacitly used in the problem solving and is shared by the involved actors. Contextual knowledge is not explicitly used, but influences the problem solving. External knowledge is that which is known by many of those involved but has nothing to do with the current problem.

In artificial intelligence (AI), context is relevant in areas such as knowledge representation, natural language processing, and intelligent information retrieval [11]. The formalization of context has been studied with the motivation of resolving the problem of generality [12], where functions are introduced for representing whether a proposition is true in a given context and the value of a term in a given context [13, 14]. The notion of lifting axioms is also presented in these works. Such axioms are used to remove the contextual dependence of some proposition or value. In the Semantic Web field, one view of context is as a local, non-shared ontology [15].

Another computer science related area where context is relevant is pervasive computing. Dey et al. [16] defines context, in the area of context-aware applications, as "Any information that can be used to characterize a situation of entities (i.e. whether a person, place or object) that are considered relative to the interaction between a user and an application, including the user and the application themselves."

3.1 Context and Ontologies

Since our previous work has been using ontologies and Semantic Web technologies to represent community data and knowledge in oral medicine, we will continue by using these technologies for modeling context. In our initial literature search, we found several initiatives for using ontologies to reason about activities in ubiquitous computing [17–19]. Contexts in the area of ontologies have also been proposed as a way of encoding local models. Bouquet et al. [15] present C-OWL, an extension of OWL, where concepts are kept local and explicit context mappings can be represented. Yet another suggested use of context in relation to ontologies, is to represent the context in which an ontology was developed, in order to ease its reuse [20].

3.2 Context in Health Care Applications

Bricon-Souf and Newman [21] review the use of context awareness in health care. They propose a simple framework for analyzing such use, and choose three main axes to characterize context, which refer to the following questions:

- What is context used for? For the purpose of the context, [21] refer to [16], where context is found to be used mainly for (i) presenting information and services to a user, (ii) executing a service, and (iii) adding context to information for later retrieval.
- What are the context items of information? Suggested items for context representation are people, environment, and activities.
- Are the context features invariant and if no, how is it possible to organize them? Features of context are complex, and can be organized further than the aspects mentioned above. Such further organization can be based on
  - Hierarchical organization, drawing on generic to specific aspects.
  - Organization according to the dimension of concept: internal aspect of context (mood of the user, state of the device), or external aspect (temperature, time, etc.).
  - Organization according to the current activity's focus, where different level of granularity are considered.
  - Organization according to the context's current usefulness, with manefesting and latent aspects.

Based on their review of existing projects that make use of context in health care, Bricon-Souf and Newman bring up a three challenges:

- The lack of recommendations about the functional needs of the context.
- The gap between basic research on context representation and the actual use of context awareness in prototypes.
- The difficulties that arise when using computerized systems for mediating human perspectives (e.g., user acceptance, the user adapting the tool for their own purposes, the cost of using the tools cannot be larger than the benefit).

3.3 Context in Computer Supported Collaborative Work

Borges et al. [22] present a framework for understanding context in CSCW. This framework is meant to guide developers to use context more systematically in designing applications. The contextual information identified are clustered into five main categories: (1) people and groups, (2) scheduled tasks, (3) the relationship between people and tasks, (4) the environment of the interactions, and (5) tasks and activities already finished.

Siebra et al. [23] have adapted this framework to computer supported collaborative learning environments (CSCLE), by adding contextual elements that are relevant to learning. For example, in the context of individuals (in the first category above), contextual elements of knowledge level and learning speed are added.

3.4 Context in Online Interactions

To personalize web sites, the user's browsing context can be used. Bothorel and Chevalier [24] describe a method where no information other than a user's current clickstream is available. A log mining method is used to combine navigation patterns with user profiles. Malzahn et al. [25] propose an ontology-based approach for linking people who have no explicit relation in a network even though they have potential common interests. This is done by integrating ontologies into social networks for shared information spaces, here online forums divided into subgroups.

4 SOMWeb

We turn now to the application domain on which our previous work has focused: supporting the members of the Swedish Oral Medicine Network (SOMNet), who are practitioners of oral medicine distributed throughout Sweden. One of their main activities is monthly telephone conferences, where ten to fifteen clinics participate to discuss interesting and difficult cases. The majority of the attendants are experts in oral medicine and the individual clinician has the opportunity to get feedback from colleagues from all over Sweden.

Originally, the only IT-support for this was the e-mailing of PowerPoint presentations, and later, an online repository of such presentations. To cater to the SOMNet members' needs, we developed SOMWeb, an online community for communication and knowledge sharing and dissemination within oral medicine. Members can add cases, with associated pictures, that are discussed at the telephone conferences. We now describe this system, as well as its basis on Semantic Web technologies, i.e., the use OWL and RDF. A lengthier description of the system and its motivations can be found in [26].

4.1 The SOMWeb System for Community Collaboration

Before the development of the SOMWeb system, the needs of the SOMNet users were charted through observations of meetings held with PowerPoint support, interviews with several members, and an online questionnaire. These needs included being able to add cases in a more structured manner, assigning cases to meetings both for initial consultation and for follow-up, and browsing the cases allocated to a given meeting. The first version of SOMWeb concentrates on supporting the telephone conferences of SOMNet. In addition to this, the case repository can also be browsed and searched in a variety of ways.

When a clinician wants to add a case to the system, he or she is presented with a blank form, generated from a community-defined template (represented in OWL, described in Sec. 4.2). This structured case entry form can be seen in the right-most screenshot of Fig. 1. There are different templates for the first time a case is entered, for entering the suggestions of the SOMNet telephone conference, and for when the clinician has more information to add about the

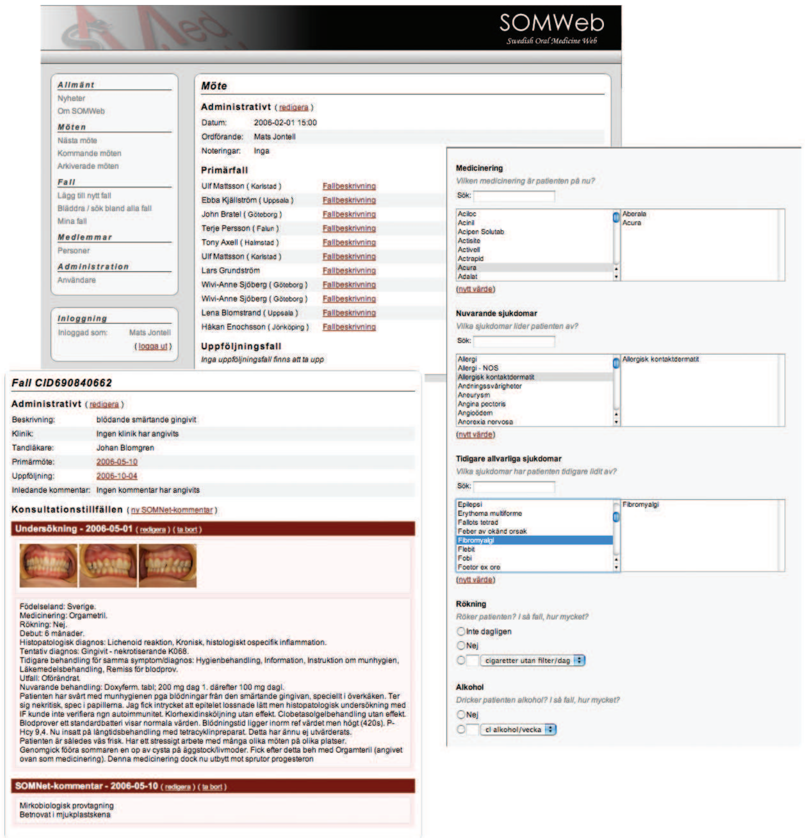

Fig. 1. The figure shows screenshots of some key parts of SOMWeb: an overview of a meeting's cases (top), a case presentation with pictures and text description generated from examination data (left), and part of an entry form for examination data (right). All text is in Swedish.

case. Upon adding a case to the system, the user can assign it to one of the upcoming meetings.

In the navigation bar found on the left of each page (see top image of Fig. 1), a link can be found to a page that lists all the previous meetings. In addition to this, there is always a link to the page for the upcoming meeting (a meeting page can be seen in the top screenshot of Fig. 1), on which administrative details about date, time, and who chairs the meeting are given. This is followed by lists of cases to be presented for the first time and then cases that are followed up from previous meetings. For each case, a short description entered by the case owner is shown, along with a link to a page with a summary of the case. On such a page, all consultations and images associated with the the case are displayed, exemplified in the screenshot at the bottom of Fig. 1. The user can also add private notes to cases.

SOMWeb also includes an online discussion forum, and a discussion thread about a case can be started from each case summary page. Meetings are scheduled by one of the organizers of the group. If, after a case has been presented, it is of interest to bring it up for consultation again, one of the administrators or the case owner can assign the case to be followed-up at a meeting in the future. The user can browse the cases of the system by looking at the cases presented at meetings, at the cases of an individual clinician, or search the examination data using free text search.

4.2 The SOMWeb ontologies

The design of the SOMWeb ontologies [27] takes the knowledge representation and content of an older system, MedView [28], as a starting point. This includes (1) examination templates that describe the pattern from which the individual records are created and which are used in constructing graphic input forms; (2) value lists, from which values can be chosen when the forms are filled out; (3) aggregates of values; and (4) individual examination records.

Each examination template in SOMWeb is stored in a separate OWL file, and there is one OWL file to define classes and properties common to all templates. A template has definitions of the categories that can or need to be included in an examination constructed from that template. For example, we have a common class `ExaminationCategory`, of which there are subclasses in the templates such as `PatientData` and `MucosAnamnesis`. We also describe inputs (or properties) in each template, along with what subclass of `ExaminationCategory` they are associated with and what classes in the value list ontology values can be chosen from. An input can also have properties with descriptions for when the input can be used and instructions that are shown when filling out the form. In value lists, all clinical terms, e.g., `Allergy`, are represented as OWL classes, with their values as instances, e.g., `PeanutAllergy`.

When analyzing collected data, value aggregates can be created and used. One may want to group, for example, medications into different categories to investigate if there are relations between these categories and mucous membrane changes in the mouth. Such aggregates are formed mainly by sub-classing the values in the value list ontology, and making the appropriate individual values instances of this subclass.

The users create these templates in a separate editor for specifying the content of examinations, and they never interact with the underlying OWL representation. After submission of a case, the case data is stored as RDF and a summary of the case information can be presented in natural language.

In addition to storing examinations in RDF, other community data – handling users, meetings, news, and case metadata – are also represented in RDF. What should be included in descriptions of users, meetings, and case metadata is described in OWL. For some of the user descriptions, relations are made to relevant classes and properties of the Friend of a Friend (FOAF) vocabulary.

5 Analysis of Current Use

5.1 Observations of Meetings

Several telephone conferences held by SOMNet were observed before and during the development of the SOMWeb community collaboration system. When the system had been used for several meetings, we studied its use at three meetings. These observations were done at the clinic of oral medicine, at the Sahlgrenska hospital in Gothenburg, where about five and ten clinicians gather in a meeting room. For each meeting, there are also between 10 and 16 other clinics participating, with usually between one and three clinicians per place. The different clinics are connected with each other by a telephone conference call and all the clinics are logged in to browse the online SOMWeb system.

The time scheduled for each meeting is about one hour, during which circa three to six cases are brought up for the first time, and zero to three cases are presented as follow-up cases from past meetings. A chairperson is assigned for each meeting. This person leads the meeting by e.g., providing transitions between presentations of cases and summing up any discussions. Online, the cases are presented in the order in which they have been entered into the system, but the actual order of presentation at the meetings is usually based on the preferences of the presenters. When presenting a case, the clinician often tells the story of his or her meetings with the patient, treatments tried, and results of these treatments. Sometimes there is a broad need for advice, sometimes more specific advice is sought, about e.g., what is important to consider for a certain treatment, and sometimes the presenter wants to raise a more general question for discussion. These presentations sometimes do not adhere closely to the way the information is presented in the system. After, and sometimes during, this short presentation, questions of clarification are asked by the other participants. Depending on the kind of case presented and what purpose the clinician had for wanting to discuss it, the meeting's participants will start suggesting possible diagnosis and treatments. Similar cases or general treatment strategies of one of the participating clinics will sometimes accompany the suggestions. A more broad discussion may ensue, about for example, the reporting of side effects for medications or whether a certain treatment is suitable in general. The chairperson usually starts summarizing when several options have been put forth, and a few suggestions are given to the presenter.

We observed mainly three purposes for presenting cases: cases of an unusual character, cases where the presenter wants to raise an issue for discussion, and cases where advice regarding diagnosis and treatment is wanted. Very few participants, apart from the chairperson, took notes at the meetings observed. Ideally, the chairperson should after each meeting make a note in the system, for each case presented, regarding what was decided, and also select a date for follow-up discussion, if this was decided at the meeting.

5.2 Questionnaire

An online questionnaire was issued to the members of SOMNet to further explore the perceived use of the SOMWeb community collaboration system. The questionnaire aimed to evaluate the current system, to discern potential ways to adopt the system further to the needs of the users, and to serve as a first step in eliciting important contextual factors and communicative activities. To announce the questionnaire, information was given on the news page of the system, e-mails were sent to the around 60 registered members, and it was introduced verbally at a telephone conference. The questionnaire was accessible for about a month. Questions concerned what goals the participants have with the collaboration as a whole (not just the SOMWeb system), self-reported details regarding system use (e.g., if their only use is in connection with telephone conferences), and how they rate the ease of use of the system. Questions pertaining to whether or not they had added cases for discussion were also included, as well as their reasons for doing or not doing so. The questionnaire was completed by 24 clinicians. Table 1 gives some demographic data for the respondents.

Table 1. Gender, position, computer familiarity, and location of workplace of the questionnaires respondents.

Gender	male/female	46/54 %
Position	specialist/general practitioner	57/43 %
Computer familiarity	very good/good/average	13/58/29 %
Workplace	private/hospital/specialist clinic/ public dental care	8/54/25/ 13 %

The respondents had an average age of 51 years. Seventy-five percent of the respondents had more than 20 years of professional experience, 17 % 10-20 years of experience, 4 % had 5-10 years of experience and 4 % had 0-5 years of experience.

In response to the question of what the respondents' primary purpose for participating in SOMNet were, 29 % answered continuing education, 63 % saw it as a forum for discussion, and 8 % replied distance consultation. These were the three options given, and only one could be chosen.

Seventy-one percent of the respondents had submitted cases to the repository. A total of 56 cases have been added to the repository, by twenty clinicians. Ten clinicians have added one case, while one clinician has added 12 cases. In answer to the free text question of reasons for submitting a case for discussion, the responses were e.g., to discuss a specific case, to discuss treatment strategies in general, and to gather information for a rare case. Reasons for not adding a case, when a participant had considered doing so, were mainly a lack of time and worry that the case in question was too ordinary or not of general interest.

6 Towards Modeling Context in SOMWeb

Our preliminary analysis of the use of SOMWeb brings us to consider how the system can be improved, e.g., so that users are motivated to contribute cases, use the system when they need information, and to further their learning from each other. We believe that a greater use of context in SOMWeb could be very relevant. Bricon-Souf and Newman's [21] simple framework for analyzing the use of context in health care applications, introduced in Sec. 3.2, can provide a starting point for structuring the use of context in our application. The purpose of adding context would be for presenting the user with information and services better suited to their needs, as well as adding context to cases, which can be used in retrieval. The following context items, in correspondence to the suggestions of [21], have been identified:

- Relating to the user, context items could include, e.g., whether the user is a general practitioner or a specialist, the location of employment (both geographically and the kind of clinic), experience (for example years working), interests, and previously added cases.
- Relating to the activity of the user, context items can be time of use (whether it is a meeting time or not), and what actions they are performing in the system (adding a case, browsing, looking for specific information).
- Relating to the environment, context items can be whether the clinician is at work or at home, the number of possible distractors, and the time available to the user. However, since our system is only accessed from a web-browser and there are few features relating to pervasive computing, the environment items are probably few.

The context of the content in the system is not given much focus in the work of [21], but for our system it is very relevant. This can be, for example, the user's purpose in adding the case. Such context could be of use both in organizing the telephone conferences to better suit the participants and when the clinician is browsing the case repository. Investigating how contextual aspects can be added to the value list ontology, to represent diverse views of users as well as different levels of granularity, is also an interesting possibility.

The organization of context features, as listed in the framework of [21], has not yet been considered. Looking at how contexts can be organized with respect to each other will be more relevant once a more thorough identification of context items has been carried out. This will be done using a more extensive literature review of context use in relation to communities of practice and health care, by observing more meetings (especially at other clinics than the one observed at thus far), and by conducting interviews with participants. In addition to the framework of [21], we believe that the framework of Borges et al. [22] for context in CSCW will be useful in organizing these context elements. The identification and acquisition of context information from a user at run time will also have to be considered, and here approaches like those in Sec. 3.4 can be of use.

In Sec. 3.1, we introduced some related work on using ontologies to represent context. For the initiatives that are in the domain of ubiquitous computing, some of the reasoning around context performed using ontologies are interesting, but the entities that are represented are at a level not relevant for us, as many of them deal with, e.g., the location of a user in a building.

Another interesting, though more complex, question is the different conceptualizations of the domain that the members may have. It would be exciting to filter the community data through different conceptualizations. Though it is probably beyond the scope of this work, C-OWL [15] may be useful for this. Also, much of the contexts that we want to model relate to the user, so user-modeling approaches using OWL (e.g., [29]), will also have to be considered.

7 Summary and Future Work

A community of practice in medicine has a large focus on knowledge sharing. We have described one such community, SOMNet, and described our previous work in developing an online system, SOMWeb, to support their knowledge sharing needs. From our experiences in developing the SOMWeb system, observing telephone conference meetings, and the users' replies to the questionnaire, we believe that modeling and using the context of the user and the cases submitted can contribute to inviting clinicians of different levels of experience to contribute and find the system useful, and that the use of the case repository for learning can be increased. We have also described some initial thoughts on what aspects of context could be relevant to represent, putting these in relation to the framework for analyzing the use of context in health care from [21]. Our long-term aims are to identify aspects of context relevant to online communities of practice in healthcare, and to investigate how these contexts can be modeled using Semantic Web technologies. We also hope to overcome some of the challenges presented by [21] (see Sec. 3.2), with regard to the use of context in health care.

In the near future, we will continue identifying relevant context items by a more extensive literature review of context use in relation to communities of practice and health care, by observing more meetings (especially at other clinics than the one observed thus far), and by conducting interviews with participants. We will then add these context items to the current ontologies of the system, both those for the community model and those that deal with clinical knowledge. A second version of the SOMWeb system will be developed, taking into greater account the context of the user in their knowledge sharing activities and the context of the information added. Finally, the system and the use of the identified contexts will be evaluated.

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Context-Aware Access Control for Collaborative Working Environments Based on Semantic Social Networks

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Abstract. Most current shared workspaces within Collaborative Working Environments (CWE) provide role-based coarse-grained access control mechanisms for eProfessionals which do not satisfy their requirements in most cases. When e-Professionals collaborate in CWE, they leave some fingerprints, which contain highly valuable information. These fingerprints can be exported and used to extract the hidden social networks based on the objects that eProfessionals collaborate upon. Social networks have great potentials to be used within different domains like designing access control policies. Context information of eProfessionals is also a great source to be used within access control mechanisms. In this paper, I present an approach for access control mechanism within CWE based on context, trust, and social networks. These are key elements for expressing access control policies. I intend to enrich the framework with Semantic Web technologies and ontologies.

Key words: Social Network, Access Control, Collaborative Working Environment, Context-Aware Access Control, Social Network Analysis, Trust in Social Network, Semantic Social Network, Social Network Mining

1 Introduction

E-professional or "eProfessional" is a term used in Europe to describe a professional whose work relies on concepts of Telework or Telecommuting: working at a distance using information and communications technology [59]. Internet has provided an infrastructure for eProfessionals to collaborate and work towards the same goal in a corporate environment which is so-called Collaborative Working Environment (CWE). The CWEs enable eProfessionals to share different resources, e.g. documents or events among other eProfessionals in a platform which is so-called shared workspaces. One of the main disadvantages of current platforms is the lack of a fine-grained access control mechanism. Most current platforms provide role-based coarse-grained access control mechanisms that do not meet the eProfessionals' requirements, e.g. temporal requirements. Social networks, which can be represented as graphs, have great potentials to be used in different domains like designing access control policies based on relationships among actors. When eProfessionals collaborate in CWE, they leave some fingerprints that are highly valuable and can be used for extracting social networks. Most current environments are able to export the activities (events) that are done as feeds or log files. The social networks among eProfessionals, extracted partially from fingerprints, and enriched with trust and context, are good candidates to be used within access control policies. The whole framework can be enriched with Semantic Web technologies to make it more machine-understandable.

In this paper, which is actually my Ph.D. proposal, first I focus on background information: I present essential definitions and concepts regarding social networks, collaborative working environments, different access control mechanisms, context-aware access controls etc. Then I consider the problem that currently exists in access control mechanism within most shared workspaces for eProfessionals and finally I have a rough overview of my approach towards solving the problem. During this paper, I try to answer following questions regarding my Ph.D. proposal:

– What is the problem that I am going to solve?
– What do I want to do?
– Why my approach is important?
– How does my approach differ from prior works?
– What do I have so far?
– How am I going to do the work?

2 Relevant Background

2.1 Social Networks and Social Acquaintances

Social networks [36], as a sort of Scale-free networks [21], can be represented as graphs using the famous notions of nodes and edges between them. Obviously, the concept of social network is not something new and its origin is not also computer science. Social networks are good means to model the connections between people based on different relationships that the actors may acquire during a period of time. The small world phenomenon [37], based on Milgram's idea of six degrees of separation [22], presents the concept that everyone in the world is connected to all people in the world by a short chain of social relationships. Some practical efforts like *The small world project* [1] at university of Columbia have proved this theoretical phenomenon. It is obviously a good indicator for the hidden power of social networks.

Roughly speaking, social networks fall into two main groups: object-centric social networks and non-object-centric which I call them user-centric social networks. The term object-centric social network has been coined by Jyri Engeström in his blog post [2] and indicates those social networks that are built on top of

[1] http://smallworld.columbia.edu/
[2] http://www.zengestrom.com/blog/2005/04/why_some_social.html

objects, e.g. the actors make a social network conceptually around a photo or a movie clip. Engeström argues that the main reason that some Web-based social network sites fail after a while is the fact that they are not object-centric and the users lose their motivations to be connected.

A social network can be analyzed based on different metrics, like *Centrality Closeness* and *Betweenness* [40], [41]. These metrics can identify different characteristics and potentials of social networks.

One of the research areas in social networks is addressing the different relationships that the actors may acquire in a period of time. Ontological consideration on human relationships has been considered by some researchers: Matsuo et al. [51] provide some consideration towards this direction and present several distinctions across relationships between humans. Davis et al. [38] introduce RELATIONSHIP which is a set of vocabularies for describing relationships between people. Carminati et al. [39] propose REL-X vocabulary, which is another effort towards this direction. Gan et al. [52] provide several vocabularies as FOAF extensions to cover the often changing variables in FOAF. This work can be considered as providing context information for FOAF profiles.

2.2 Collaborative Working Environment

Collaborative Working Environments (CWE) are platforms and infrastructures that support working between people (eProfessionals) by means of different technologies and tools. The CWE was in existence before the birth of computers and Internet. The concept of e-Collaboration, which first appeared in 1980s, have been studied by many researchers. Kock [42] defines e-Collaboration and has an overview of six key conceptual elements of e-Collaboration.

2.3 Semantic Web and Semantic Social Network

Semantic Web [1], as an extension to current Web, is actually a set of technologies and standards which tries to help machines to understand concepts and extract new information based on existing well-defined information. Using Semantic Web, software engineers are able to build interoperable systems that can benefit from machines to combine data and reason on existing data and infer new information. Ontologies are main building blocks and fundamental elements of Semantic Web and try to define a specific domain in a systematic way. Ontologies can be represented using different standards and languages like RDFS [3] and OWL [2]. Both are based on Resource Description Framework (RDF) [63] which is a language for representing information about resources. OWL comes in three main flavors: OWL Lite, OWL DL and OWL Full which have been sorted according to expressivity and complexity levels.

Combining Semantic Web and social networks is an interesting area for many researchers. One of the main initiatives towards building a semantic social network is FOAF [3] (Friend of a Friend) project [44]. In brief, FOAF provides some

[3] `http://www.foaf-project.org/`

basic vocabularies that are needed to describe people, their interests, their friends etc. Efforts like XFN [4] (XHTML Friends Network) tries to embed social networks and human relationships using hyperlinks like HTML. Neumann et al. [9] compare different online social networks based on different criteria and try to conclude with the importance of combining social networks and Semantic Web portals for a better collaboration in online communities. Downes [10] tries to address the need of social network metadata within semantic metadata. Jung et al. [14] propose a three-layer architecture (social layer, ontology layer, and concept layer) for semantic social networks which all these three layers are connected together and can influence each other. In [62] Mika extends the model of ontologies with social dimension and shows how community-based semantics can appear from this new model through a process of graph transformation.

Most researchers [47], [46], [50] in this area use FOAF as a basis model and extend it partially and gather a benchmarking corpus from extracted information which is available mostly on the Internet. Mika [13], [48] did some work on mining social networks based on a hybrid approach from FOAF profiles and also information extracted from Google and ranked through Google Mindshare [45] for building and analyzing social networks among Semantic Web researchers (Flink [5] project). Due to availability of semantic search engines and open data like [49], this approach sounds to be more interesting among others. Goecks et al. [54] provide an infrastructure that uses social networks for information sharing. They extract social networks from users' email messages. Mori et al. [53] have the similar approach, but they use different sources like Web pages, emails, sensors and enable users to control their resources. This is performed automatically, but end users can also access and obviously change their social networks.

2.4 Trust in Social Networks and Semantic Web

One of the most famous works in defining a computational model of trust is [11]. In this work, Marsh took into the account the concept of trust in different domains and based on this consideration, he developed a trust model for a distributed environment. In [12], Golbeck has studied trust in social networks and proposed several algorithms for computing trust in social networks and evaluated this model using some applications like TrustMail.

Trust and Semantic Web have been studied in different domains, mainly for recommendation systems. In [4], Bedi et al. suggest a semantic recommendation system based on trust and they apply their model to a tourism recommender system which generates recommendations for a selection of destinations.

2.5 Context in Social Networks and CWE

It is difficult to give one valid global definition to context. The main reason is that there is no absolute context and context gets its meaning in relative to

[4] `http://gmpg.org/xfn/`
[5] `http://flink.semanticweb.org/`

something [64]. The lack of sufficient literature on studying the roles of contexts and contextualizations in social networks is apparent. There exist some works like [5], [6], [7] which try to address some aspects of contextualizations in social networks, but they seem to be preliminary works. Using shared context in CWE to improve and support collaborative tasks has been also studied in some works like [8].

2.6 Access Control

Access control is the ability to permit or deny the use of something by someone [43]. There exist plenty of approaches and mechanisms towards controlling the access: access control lists, role-based access control, attribute-based access control, ontology-based access control etc. There exist a lot of formal languages that aim to express access control policies with different perspectives and granularities, like XACML [56], which is an extensible access control language and is currently used in many frameworks, P3P [57], which is too coarse-grained to be used in different domains, EPAL [55], which is more machine-readable, Rei [58], which is an ontlogy-based policy language, and KAoS [60], which is another ontology-based policy framework which is well-suited for Semantic Web services etc. Many researchers try to combine different access control mechanisms to build a more powerful mechanism and decrease the disadvantages of each mechanism. Kern et al. [23] provide an architecture for role-based access control to use different rules to extract dynamic roles. Alotaiby et al. [29] present a team-based access control which is built upon role-based access control. Periorellis et al. [30] introduce another extension to role-based access control which is called task-based access control. They discuss task-based access control as a mechanism for dynamic virtual organisation scenarios. Kim et al. [34] propose a collaborative role-based access control (C-RBAC) model for distributed systems which is fine-grained and try to address the conflicts from cross-domain role-to-role translation. Toninelli et al. [61] present an approach towards combining rule-based and ontology-based policies in pervasive environments.

There exist some efforts towards enriching access control mechanisms by means of Semantic Web technologies. Li et al. [25] propose a rule based access control which is based on OWL and SWRL [26]. They propose an OWL ontology to describe the terms and access policy rules will be expressed in SWRL. Priebe et al. [31] discuss that attribute-based access control (ABAC) is a bit complex and error-prone and they propose a solution by pushing Semantic Web technologies and ontologies into ABAC.

The study of access control mechanisms in CWE is not new and was in existence from the birth of e-Collaboration. Shen et al. [33] studied access control mechanisms in a simple collaborative environment, i.e. a simple collaborative text editing environment. Zhao [20] has an overview on three main access control mechanisms and provides a comparison between these three main mechanisms in collaborative environments. Tolone et al. [19] provide a comprehensive study on access control mechanisms in collaborative systems and they compare different mechanisms based to different criteria, e.g. complexity, understandability, ease of use, etc. There exist also different studies on access control requirements in collaborative systems. Jaeger et al. [28] present basic requirements for role-based access control within collaborative systems. Gutiérrez Vela et al. [32] try to model an organization in a formal way that considers the necessary elements to represent the authorization and access control policies. Demchenko et al. [35] propose an access control model and mechanism for grid-based collaborative applications.

There exist some studies on access control in social networks. Most of the literature focus on relationships that the people may acquire in a social network. In [18], Kruk et al. suggest a role-based policy-based access control for social networks, where the access rights will be determined based on social links and trust levels between people. In [15], Carminati et al. present the same approach and in [16], they extend their model by adding the concept of private relationships in access control, as they noticed that all relationships within social networks should not be public, due to security and privacy reasons.

Using context information in access control mechanisms has been studied by different researchers. Toninelli et al. [17] suggest a semantic context-aware access control framework for secure collaboration in pervasive computing environments. They propose a simple OWL-based context model and based on this model, they propose a context-aware policy model and they support their model by a meeting scenario case study, where the attending people can access the meeting resources only during the meeting. They express policy statements using description logic. Georgiadis et al. [24] provide a model for combining contextual information with team-based access control and they provide a scenario in health care domain, where the model is used. Zhang et al. [27] propose a model for dynamic context-aware role-based access control for pervasive applications. They extend role-based access control and dynamically align role and permission assignments based on context information.

3 Problem

In a collaborative working environment, where the eProfessionals collaborate, there should exist some kind of access control mechanism, as eProfessionals share different resources (e.g. profiles information, documents, events, etc.) and shared resources should be protected against unauthorized accesses within shared workspaces. Most current shared workspaces provide a coarse-grained role-based access control mechanism which is not flexible and in most cases seems to be effectless, especially when the number of eProfessionals increases.

I present a scenario to explain this problem in a more detailed manner: Bob is the name of the main actor. He is currently working on an European project in a collaborative distributed infrastructure with other team members from different organizations. Partners are geographically distributed in different countries with different time zones. This project has different Work Packages (WP) and Bob is the leader of WP two. The project has a Web site for public visitors. This Web site includes project news, newsletters, public events, some public deliverables and information about the scope and the mission of the project. The project has also a private collaborative working environment (shared workspace). The private side includes a wiki, a forum, a calendar to document events, some folders for uploading documents to be accessed by team members, a bunch of documents, presentations, photos from meetings, contracts, time sheets etc. Partners have sometimes conference calls to discuss online or via telephone. They meet regularly each two/three months to setup things and discuss the progress of the project. In this private workspace, Bob has uploaded some documents, photos, and presentations. The issue is that not all project members should access Bob's resources. In our case, Bob wants to set the following access control rules based on the roles defined by the project.

- Bob wants to give access of work-in-progress deliverables to all WP leaders plus the project coordinator and if some of them are not available (e.g. on vacation), to their proxies.
- Bob wants to give access of a confidential contract only *once* and only to a specific person.
- Bob wants to give access of a particular presentation only during the meeting (temporal restrictions) and only to specific meeting participants.
- Bob wants to give access of a particular background document only to members that are currently working on a particular deliverable.
- Bob wants to share a photo only to his close friends (or his colleagues from his company) within this project.
- Bob wants to give access of his presentation, only after finishing it and only to particular members.
- Bob does not want to give access of a document to friends that were not present in a particular meeting and their trust levels are less than a threshold.
- Special rule: Bob wants to share a technical report with responsible persons from other projects that are related to his project (same domain)
- and more rules ...

The above items are just some simple requirements for setting access control policies. In general, with current role-based access control mechanisms within most CWEs (shared workspaces), it seems to be very difficult or even impossible to apply above rules. The lack of a fine-grained access control mechanism for shared workspaces within collaborative working environments is the main problem that I want to address in my thesis. The term *fine-grained* refers to a flexible, parametric, context-aware, open and extensible access control mechanism. Towards this direction, in next section, I explain how social networks within most CWEs and context information can help to express and apply more flexible access control rules.

4 Approach

Generally, to realize above scenario, I plan to build a context-aware access control for shared workspaces within collaborative working environments based on social networks. Social networks are key players, as their model is very similar to what we utilize in our offline lives to give access to the people that we communicate with. To achieve this goal, the first problem that should be addressed is modeling social networks in different layers: based on social acquaintances and also roles within a collaborative working environment and organization. Besides this user-defined (manual) social network, there exist also some (semi-)automated ways to extract the *hidden* social networks in shared workspaces. This hidden social network, which connects people by means of dynamic relationships, is based on the *objects* that connect people (i.e. object-centric social networks), and can be extracted using different mechanisms, like processing the log files and feeds. As an example, if user A reads a document that has been written by user B, the hidden relationship between two users is "ReadWrite" from user A to user B and "WriteRead" from user B to user A. These hidden relationships enable building parametric social networks and help to *recommend* the appropriate candidates for sharing resources.

One key candidate for representing social networks is an extended version of FOAF to meet the new requirements. I believe that this area (mining social network) is a very wide area and different sources can be considered towards this direction, but the main focus of my thesis is not on this section. In this step, I will have an overview of possibilities for defining/mining social networks from shared workspaces and provide a simple proof of concept. This approach should benefit from ontologies for machine-understandability, like an ontology for different sources that help to build social networks, an ontology for properties of a graph, etc.

The next problem is defining a context model that is extensible and suitable enough to model context information of eProfessionals with regards to CWE. This model should contain all required context information that is helpful for expressing access control policies. Obviously, this model and the model of social networks should refer to each other.

The analysis of social networks based on different criteria that make sense for access control and then calculating trust among eProfessionals based on their dynamic relationships are the next sub-problems that should be solved. Different characteristics of social networks should be considered to check whether they make sense to be embedded in access control scenarios or not. These characteristics vary from those related to graph-theory (e.g. in-degree, out-degree) to new defined ones.

One of the main goals is to allow end users to express access control policies based on context information, trust and social network analysis. Probably ontology-based description which is actually a logic-based approach is a key candidate towards this direction.

The final step is related to the construction of the main engine that gets the enriched social networks and access control rules as inputs and decides the accessibility of resources for different users. Figure 1 demonstrates the overall view and the whole process that I plan to work on it.

To summarize, below I present a list of items that are related to my research:

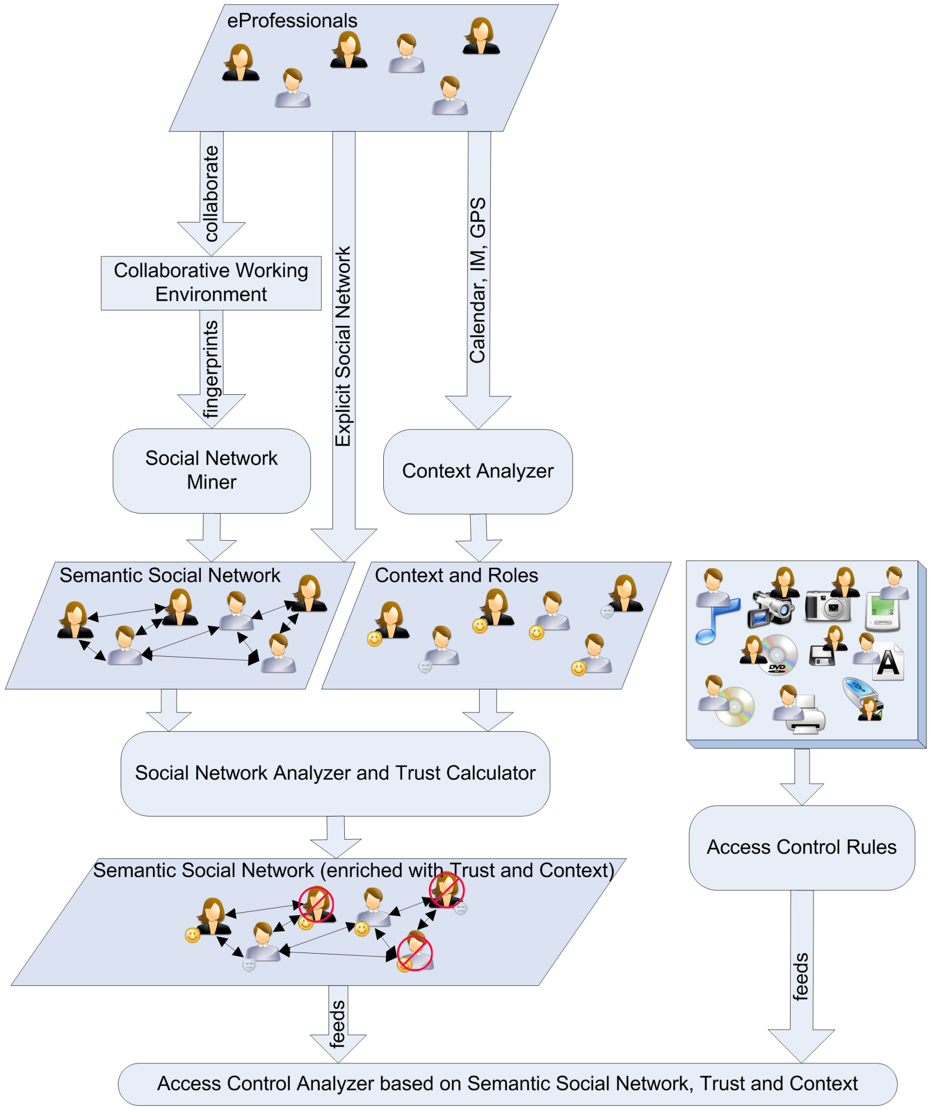

Fig. 1. General Overview of Solution

- Modeling the collaborative working environment as social networks
- Mining social networks from shared workspaces within CWEs based on the objects that eProfessionals collaborate upon and the different roles that they acquire
- Modeling the required CWE context information
- Proposing trust criteria for different characteristics and dynamic relationships in social networks within CWEs

– Expressing access control rules with consideration of the model of social network, trust and context criteria
– Designing an engine that gets access control rules and enriched social networks as inputs and decides the accessibility of resources for different users
– Supporting all layers with semantic technologies to make relevant information more machine-understandable

5 Conclusion

Most current shared workspaces within CWEs provide a role-based access control mechanism which is in most cases inflexible and effectless. Social networks and contexts are two main candidates to enrich the legacy access control mechanism for a more flexible approach. In this paper, I discussed the lack of a fine-grained context-aware access control for CWEs using a scenario and based on requirements, I proposed a context-aware access control mechanism based on social networks within CWEs. In my approach, context information of eProfessionals, trust, and explicit and implicit social networks within CWEs are key concepts. The implicit social network can be extracted by monitoring the behaviors of eProfessionals, when they collaborate in CWEs. I enrich the framework with Semantic Web technologies and ontologies. This approach enables users to express and apply flexible access control rules based on their relationships with other eProfessionals, trust and their context information.

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Context-aware Handling of Different Viewpoints in Learning

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Abstract. This PhD proposal aims to define a dialectic approach to exploit discrepancies in viewpoints derived from different conceptualisations of the same domain for learning. Differences in conceptualisations may arise due to differences in the context in which conceptualisations are developed. A computational framework of a pedagogical agent capable of interacting with a learner for discussing different viewpoints and exploring the context in which these viewpoints hold is outlined. The framework employs AI technologies, such as argumentation for defeasible reasoning, situation calculus for contextualized reasoning and dialogue management. The approach can be applied in interactive learning environments to promote awareness, reflection, and conceptual change.

Key words: viewpoints, conceptual discrepancies, argumentation, context, e-learning

1 Introduction

The advancements of the Semantic Web Technologies have recently led to the development of advanced educational systems that offer personalised learning experiences tailored to the needs of individual users [1]. Such systems take advantage of domain conceptualisations provided in the form of ontologies. However, studies show that conceptualisations may differ between tutors and the resources they prepare [2], as well as between a learner and a tutor [3]. Recent research acknowledges that different conceptualisations can be associated with particular context, within which valid claims are formed [4]. Variations in context, which in turn lead to variations in domain conceptualisations, can be associated with differences in the background knowledge of tutors and learners, incompleteness of domain knowledge, or differences in the intented use of the domain ontology.

In our research, we consider that the awareness of alternative views can bring educational benefits by broadening the perspective of learners. We argue that discrepancies in conceptualisations can be handled constructively to enrich the learning experience in educational systems. We propose an approach where a software agent detects discrepancies in conceptual viewpoints of a learner, tutor, and learning resources, and engages in a dialogue to explore similarities and differences between different viewpoints.

The paper reviews related work for dealing with different viewpoints in learning systems and proposes a dialectic approach for handling viewpoints in educational semantic web applications. Then, it outlines the proposed research approach. Next it states the research goal of this proposal and lists the research questions that need to be addressed. Section 5, describes the proposed framework for dialectic handling of viewpoint discrepancies. The architecture of a dialogue agent that explores different viewpoints in a conversation with a learner will be outlined. We will illustrate the use of AI technologies, such as argumentation for defeasible reasoning, situation calculus for contextualized reasoning and dialogue management, to exploit viewpoint discrepancies in learning. Section 6 focuses on current and future work. The expected contributioin is outlined in section section 7.

2 Related Work

The first attempts to deal with viewpoints in learning can be traced back to some of the early Intelligent Tutoring Systems (ITSs) [5]. Among these, two notable uses of viewpoints were shown by the systems VIPER[6] and DENISE[7]. In VIPER, viewpoints represent different interpretations of domain knowledge. However, viewpoints are fixed in advance and refer only to the domain expertise. In contrast, DENISE[7] is capable of learning different viewpoints from the user and the system may or may not have its own domain model. Where the domain knowledge exists, it may differ from the point of view expressed by the user. A formal way for representing viewpoints in ITS is given in [8] where the viewpoint of an agent a is defined as a triple $Va =< Ba, La, Ma >$ with each element being a subset of the agent's complete belief, logic and meta-logic space, respectively.

While the early ITS research on viewpoints considers different perspectives of the domain and offers representations that distinguish between the tutor's and learner's viewpoints, these projects suffer from two key limitations. Firstly, any deviation of the view of the student from the view of the tutor is considered as a *bug* that needs to be fixed. In case where the learner is allowed to add her own viewpoint of the domain, she is not provided the means to support her own viewpoint or compare and contrast with other viewpoints. Secondly, the early ITS systems adopt rather static approaches for dealing with viewpoints, e.g. transmitting the tutor's viewpoint by telling it to the student and assuming that it will overwrite the student's own[9].

The emergence of collaborative learning systems facilitated the discussion and exchange of different points of view among peers. Based on research in Education which advocates the use of argumentation for constructive learning, collaborative learning systems were implemented to enable and encourage the use of argumentation for joined decision making and sharing of knowledge, e.g. [10–12]. Empirical evidence from the use of these systems suggests that the exchange and challenge of different viewpoints via argumentation motivates the processes of reflection, articulation and conceptual change.

Collaborative learning environments have influenced the design of computational approaches for developing intelligent pedagogical agents that support viewpoint clarification. These approaches can be classified in two groups. *Mediating agents* which monitor discussions between peers [13], identify conflicts in viewpoints [14], or offer actions that can help resolve conflicts [15]. *Dialogue agents* which engage in conversations with the learner to clarify different views about the domain [16], opinions about the learner's beliefs [17], or inconsistencies in the learner's viewpoints [18]. In their great majority, these systems addressed the importance of argumentation for learning.

Although these systems aim to sharpen the learner's critical skills, they typically provide very limited analysis of the discussion. They do not model the learners' beliefs during the interaction and do not provide any automatic support to facilitate articulation and clarification of different views about the domain. In addition, since these approaches stemmed out of the education domain in their majority, they are not based on a systematic theory of argumentation, studied in depth by various branches of the AI community. Effectively, despite the notable successes, the existing computational approaches do not fully address the problem of identifying and clarifying viewpoints because they do not explore the context in which the views have been formed and ignore what arguments have led the learner/tutor to form a particular position. Moreover, none of these approaches is SW-compliant, so additional work is required to make them ontology-based and to integrate them in educational SW applications, as illustrated in [3].

This leads us to the conclusion that a more radical approach is needed to deal with differences in viewpoints for the purposes of learning, i.e. one that involves the learner in the discussion of different viewpoints, clarifies discrepancies in viewpoints and provides automatic support to facilitate clarification, justification and support of different viewpoints. Formal dialogue systems can be used to provide automatic support for articulation and clarification of differences in viewpoints via the use of argumentation and were investigated in a wide spectrum of inter-disciplanatory AI areas, e.g. multi-agent systems, AI in Legal reasoning and medical diagnosis.

Initial work on formal models of dialogue using argumentation derived from the Philosophical logic domain. These dialogue models were primarily models of pursuation dialogues (Mackenzie [19], Walton and Krabbe [20] etc). Walton and Krabbe[20] derived a typology of inter-personal dialogue games, which included among others *deliberation*, *negotiation* and *pursuation* dialogues. Computational models of the aforementioned type of dialogues were later developed in the area of multi-agent systems and can be traced to the works [21], [22, 23], and [24], respectively. Although the benefits of pursuation dialogues are well recognised in areas like e-commerce, and legal reasoning, they dont form suitable dialogue models for educational settings. This realisation led to the conception of a new type of dialogues, referred to as *education dialogues* by Parsons et al. [25]. Their work focuses on tactics of tutors use in coaxing the learner to progress by asking questions that the learner has not previously answered[25]. Our focus is on using *education dialogues* for the discussion, clarification and comparison of different viewpoints.

3 Proposed Approach

Building on research in dialogue pedagogical agents, Semantic Web, and argumentation, we propose a dialectic approach for exploiting viewpoint discrepancies for learning. Specifically, we propose that conversational agents should engage in discussions with the learner to clarify different positions about the domain by identifying sources, beliefs and arguments that have led to these positions. Through such interactions, the learner will articulate her domain knowledge, become aware of differences and similarities in viewpoints, question the validity of her beliefs, and reflect on her knowledge. The distinctive characteristics of the proposed approach are:

- the targeted domain knowledge appears in the form of conceptualisations consisting of a set of concepts, their relationships and properties, and is represented via the use of ontologies;
- multiple perspectives of the domain are catered for, which is addressed in the dialogue planning and the maintennace of the agents' viewpoints;
- the interaction adopts appropriate argumentation methods to clarify and differentiate between viewpoints;
- discrepancies in the leaner and tutor's conceptualisations are not considered as bugs but as triggers for dialogue games that clarify alternative views.

4 Research Goal and Research Questions

The research goal, research questions and pedagogical objectives of this PhD are described below:

Research Goal. We will develop a computational framework for the design of a tutoring agent who engages in discussions to clarify different viewpoints and make the learner aware of the similarities and differences between them. We will then show how this framework can be applied to educational semantic web systems to help learners make links between learning objects and become aware of different perspectives of content and ontologies.

Research Questions. This PhD project will address the following research questions:

- How can we derive a computational framework to identify discrepancies between viewpoints?
- How can we manage educational dialogues for handling discrepancies between viewpoints of a tutor, a learner and learning objects?
- How can the computational framework be applied in educational scenarios and what benefit will this bring?

Pedagogical Objectives. Empirical evidence[26] has shown that in order for collaborative argumentation to be effective in supporting conceptual change and development in Science [27] there is a need to deploy didactic tactics in dialogue games in order to address incompleteness and inconsistencies in the learner's explanatory model. This PhD aims to develop dialogue strategies that pursue the following list of pedagogical objectives:

- *Articulation*[28] By engaging in discussions that clarify viewpoints learners make their views or beliefs explicit.
- *Reflection* [29] By providing explanations or making beliefs explicit, learners reflect on their own arguments and reasoning. Learners that engage in these activity show the most learning benefits.
- *Change in View*[28] During the dialogue, either of the participants may adopt new beliefs or revise old ones.
- *Conceptual Change*[28] Conceptual change is achieved through the processes of differentiation, generalisation, and partitioning of the universe of reference.

5 Framework for Dialectic Handling of Viewpoint Discrepancies

We will outline here the main components of a framework for the design of a tutoring agent A that is engaging in discussions with a learner L to clarify different viewpoints taking into account the context in which these viewpoints have been derived. We will briefly discuss methodologies that will be used for the formalisation and will give examples of some of the definitions which form part of the current work in progress.

We will consider the case where the agent A can be integrated in an educational semantic web system, e.g. an adaptive recommender system like OntoAIMS [3]. The agent A has a domain ontology Ω_A representing the main concepts and relations in the domain (currently, we use the ontology about Programming Languages from one of the instantiations of STyLE-OLM [30] [1]). The learner L is reading through recommended resources and may get confused about statements in these resources. L can then initiate a discussion with A to discuss the validity of statements made in the learning resources R.

In order to illustrate the definitions in this section, we will use the following extract which is taken from an example elaborated in [31]:

(1) **L:** Let us Discuss the statement in Resource: URI_1: *VB is an OOL*.
(2) **A:** What is the explanation given in the Resource URI_1 for *VB is an OOL*?
(3) **L:** The resource URI_1 states that *VB is an OOL* because *VB contains Objects*.
(4) **A:** So do you agree that *VB includes objects*?
(5) **L:** Yes..I agree that *VB includes objects*
(6) **A:** Do you agree that a *PL is OOL* because it *contains objects*?
(7) **L:** I disagree with this.
(8) **A:** OK, do you agree that *contains objects* is necessary for a PL to be OOL?
(9) **L:** Yes.

[1] STyLE-OLM uses a dialogue agent that discusses a conceptual domain with a learner and derives a learner model.

(10) **A:** What other condition is needed for a PL to be OOL?
(11) **L:** OOL have the *property of 'encapsulation'*
(12) **A:** So, you think that *IF a PL contains objects AND PL has the property of encapsulation THEN PL is an OOL*
(13) **L:** Yes, that's it!
(14) **A:** Therefore, you think that *IF VB has the property of encapsulation THEN VB is an OO Language*
(15) **L:** Yes.

The proposed architecture of the framework is given in figure 1. It includes four main components:

- *Interface module* which analyses the utterances made by the learner and creates an internal representation of the move corresponding to each utterance.
- *Commitment maintenance module* which is responsible for the creation and update of the commitments of the dialogue participants.
- *Viewpoint maintenance* which creates, retrieves, and updates the viewpoints of the learner, tutor, and learning resources.
- *Dialogue management and situation update* which takes into account tutoring strategies and decides what dialogue move should be performed next by the tutor based on the current situation.

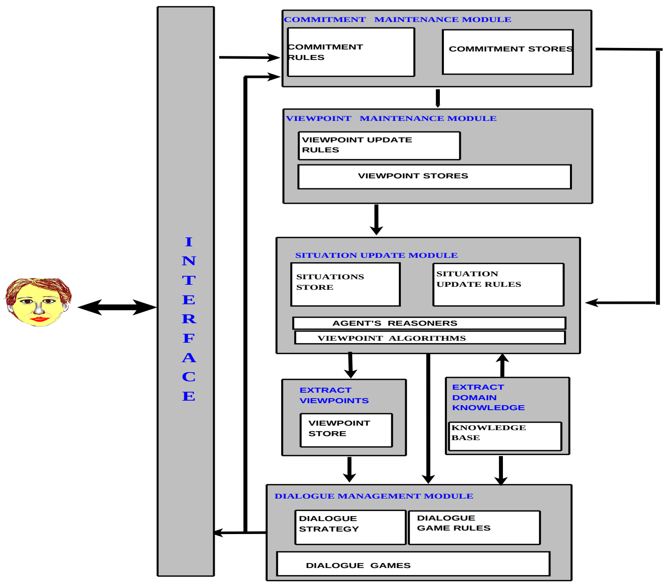

Fig. 1. Proposed Architecture of a Framework for Dialectic Viewpoints Handling

5.1 Interface

We assume that both the learner and the tutoring agent are provided with an appropriate interface to compose their utterances that express dialogue moves.

In line with existing computational approaches, e.g. [13, 15, 17, 3], we assume that the interaction is restricted to the use of predefined moves where each move is associated with several possible sentence openers. Possible moves and their associated sentence openers are given in Table 1, more details are presented in [32]. In addition, we assume that the interface provides an appropriate way for the dialogue participants to compose the propositions of their dialogue moves, e.g. by using structured sentences or graphical statements [3].

Sentence Openers and Statement templates	**Move type**	Move SubType
Let us Discuss the statement in Resource ____	Inform	Discuss
The resource ____ states that ____ because__	Inform	Clarify
Yes, I agree that__	Inform	Concede
I disagree that__	Inform	Disagree
I disagree.	Inform	Disagree
I think that__	Inform	Claim
Because the property ____ is necessary for__	Inform	Justify
Then I think that__	Inform	Conclude
Yes, Thats it!	Motivate	Reinforce
I cant think of anything else.	Inform	Meta-cognitive
What is the explanation given in Resource ____ **for** *____*	Question	Clarification
So do you agree that	Question	Agreement
Do you agree that Property ____ is a necessary property for ____	Question	Clarification
Do you agree that Properties ____ are necessary and sufficient properties for ____	Question	Clarification
Why?	Question	Explanation
So, do you think that ____	Question	Clarification
Therefore you think that____	Question	Conclusion
Why do you think that	Question	Explain
What do you know about the property ____	Question	Property definition

Table 1. Example sentence openers and dialogue move types.

A **move** m is defined as a tuple $m =< n, a, t, \varphi >$, representing its unique identifier which is a number n, the agent a who produces the move, the move type t that is linked to possible sentence openers, and the statement φ. To make a statement that a proposition p is valid in a particular context C we will use the predicate $ist(C, p)$ [4]. For instance, the first two moves in the example above express statements about the resource R and are defined as follows:

$m_1 =< 1, L, informDiscuss, ist(R, instance\_of(VB, OOL)) >$
$m_2 =< 2, A, questionExplore, ist(R, instance\_of(VB, OOL)) >$

Influenced by the theory of speech acts[33] which interprets utterances as actions aimed to bring about a particular effect to the hearer, and following the approach in Brewka's framework which is based the situation calculus for describing actions, we will define axioms that state: (i) the conditions necessary for the dialogue moves to be possible and (ii) the effects that the moves have on each of the participants.

The definition of axioms describing the conditions and effects of the set of moves presented in Table 1 is part of our current work in progress. The example below illustrates the definition of an *iDiscuss* move which defines a speech act incurred by the learner in order to initiate a dialogue game to discuss a particular position. The move refers to move **(1)** of the above example. The fluents *premiss* and *possible* used in the following axioms denote the premise which is accepted in a particular situation and the circumstances under which a move may be executed, respectively. These are defined in [34].

$possible(iDiscuss(A, ist(R, instance\_of(vb, ool)), S_i) \equiv$
$\neg premiss(A, \neg ist(R, instance\_of(vb, ool)), S_j)) where\ S_j\ happens\ before\ S_i$

i.e. it is possible for agent A to discuss the premiss $ist(R, instance\_of(vb, ool))$ in situation S_i if he has not already accepted $\neg ist(R, instance\_of(vb, ool))$ in situation S_j.

$premiss(A, ist(R, instance\_of(vb, ool)), do(iDiscuss(A, ist(R, instance\_of(vb, ool))), S_i))$

where the fluent *premiss* represents the situation where the agent, A accepts the premise $ist(R, instance\_of(vb, ool))$ in the situation that results from executing move $iDiscuss$ in situation S_i.

5.2 Commitment maintenance

The beliefs of both participants derived from the dialogue are stored in commitment stores, and are used to compose the viewpoints or to plan the dialogue. Similarly to [17, 3], we employ commitment rules to establish the beliefs to which the participants of the dialogue are committed by taking into account the current dialogue move and the dialogue history. The agent's commitments are also derived from its domain ontology Ω_A. For example, after m_1 above takes place, the following changes in the commitment stores of the participants of the dialogue take place:

$CS_L = CS_L \cup B_L(ist(R, instance\_of(VB, OOL)$
$CS_T = CS_T \cup B_T B_L(ist(R, instance\_of(VB, OOL)$
(where CS_L and CS_T denote the commitment stores of the learner and the tutor, respectively; similarly the modalities B_L, B_T denote the statements 'the learner believes that' and 'the tutor believes that' respectively).

5.3 Viewpoint maintenance

The maintenance of viewpoints includes a set of operations over the viewpoint stores to add, delete, update, and revise viewpoints. Viewpoint definition and the mechanism for obtaining and maintenance of viewpoints is a core part of our framework. Viewpoints will be defined in a way that enables the agent to compare two viewpoints and identify similarities and differences between them.

A **viewpoint** $\mathcal{V}$ is defined as a structure $\mathcal{V} \equiv < s, p, B, \Gamma >$ where: s denotes the source of the viewpoint (e.g. the learner, the agent, or an existing learning resource), p denotes the position of the viewpoint represented with a proposition (e.g. *'VB is OOL'*), B is a set of beliefs of s related to p (e.g. *'All OOL have objects'*), and Γ is a set of arguments of s supporting the position p.

We illustrate the structure of viewpoints by showing the viewpoints of the resource and the learner respectively obtained from the dialogue extract above.

$\mathcal{V}_R \equiv$ **Viewpoint of resource** R	
Source s_R	R
Position p_R	`instance_of(VB,OOL)`
Belief set B_R:	
	`has_property(VB, contain_objects)`
Argument set Γ_R:	
$claim_1$	`instance_of(VB,OOL)`
$datum_1$	`has_property(VB, contain_objects)`
$warrant_1$	$\forall X$: `has_property(X, contain_objects)` $\Rightarrow$ `instance_of(X,OOL)`

$\mathcal{V}_L \equiv$ **Viewpoint of Learner** L	
Source s_L	L
Position p_L	`? instance_of(VB,OOL)`
Belief set B_L:	

	`has_property(VB, contain_objects)`
	`has_property(OOL, contain_objects)`
	`has_property(OOL, encapsulation)`

Argument set Γ_L:	
$claim_1$	`has_property(VB,encapsulation)` $\rightarrow$ `instance_of(VB,OOL)`

$datum_1$	`has_property(VB,contain_objects)`
	`has_property(OOL,contain_objects)`
	`has_property(OOL,encapsulation)`

$warrant_1$	$\forall X$: `has_property(X,contain_objects)` $\wedge$ `has_property(X,encapsulation)` $\Rightarrow$ `instance_of(X,OOL)`

The above examples of viewpoints make use of the Toulmin's[35] structure of argument, which is considered suitable for our purposes because it makes a distinction between grounded beliefs (i.e. datum), and generalised assumptions (i.e. warrants) which can be used to deduce the conclusion (or claim) of the argument.

5.4 Dialogue management and situation update

The dialogue is organised as a sequence of dialogue games which in turn are sequences of dialogue moves. Intuitively, dialogue games are goal oriented units specifying the kind of language interactions in which people engage. Each game pursues a particular goal and is initiated and terminated when certain situations pertain. Based on the state of the commitment stores and the viewpoint stores, the agent collects information about the current situation and uses this information in order to plan the future dialogue and update the existing viewpoints. Situation update takes place after each dialogue move in order to take into account the effects of each move.

Our endeavor to thrive a suitable computational model of argumentation for this PhD project is influenced by the generic computational model of argumentation advocated by Brewka, in [34]. This particular model was considered suitable for our work because of the following reasons:

- It suggests a model of argumentation based on situation calculus which is appropriate for modelling the effects of actions (in our case speech acts[33]) in non-deterministic environments.
- It enables the use of argumentation to suggest or attack particular claims.
- It makes use of the notion of preferences between arguments that enables the choice between attacking arguments.
- It can be adapted and extended to incorporate the particular features of disputation (collaborative, argumentative) that we wish to employ.

What information will situations have in this thesis? In our framework we intend to capture discrepancies in conceptualisations and show how the cognitive states of agents change as a result of the interactions between the human and the software agent. *Situations* will be used to describe the cognitive states of agents, and will show any differences in opinions and discrepancies in viewpoints.

Areas where the model is unsuitable: The computational model in [34] is intended to be general enough to be applicable independently of the logic of disputation adopted in each particular application. However, it is very much influenced by the Rescher's theory of formal disputation[36]. According to this theory, a *debate* needs to take place between two participants (an opponent and a proponent) which are expected to pursue their initial opposing positions throughout the dialogue. A determiner will then declare the winner based on the plausibility of arguments placed by the players. Albeit the fact that this notion of *debate* finds itself suitable in other domains, like for example in legal reasoning, it does not form a suitable model of debate for learning environments aiming to bring participants with different competences together in order to discuss, clarify and reflect on their positions. For this reason, an appropriate adaptation of the model is considered necessary.

Extensions and adaptation of the model: In order to use the computational model discussed above we need to address the following issues :

– Provide an appropriate set of speech acts suitable to capture differences in viewpoints,
– Employ an appropriate structure of argument to represent arguments in our model e.g. Toulmin's model of argument,
– Employ an appropriate argumentation framework and extend it with suitable preference semantics - the Dung's notions of defeat, attack etc of argumentation seems the most appropriate,
– Use appropriate argumentation schemes to derive defeasible arguments, e.g. Use the Walton's argument scheme 'appeal to expertise' to warrant arguments supported by competent expert opinion (e.g. other tutors).
– Change the rules of the debate so as to allow for collaborative argumentation in learning.

The importance of an appropriate set of speech acts to enable the participants to clarify and discuss their positions is obvious and it is already mentioned in section 5.1. Also, the Toulmin's structure of argument was illustrated as part of the viewpoints of the Resource and Learner captured as part of the example dialogue extract (in section 5.3). The argumentation framework will need to take into account domain characteristics and for this reason, it will be developed as part of this project.

An **argumentation framework** is a structure $< AR, attacks >$ where AR denotes a set of arguments and *attacks* is a binary relation on AR, i.e. $attacks \subseteq AR \times AR$[37]. We will employ Dung's [37] theory of attack and defeat because:

- The theory is not dependent on the internal structure of arguments - thus we can employ the structure of argument that is more suitable in an interactive learning environment.
- The theory is amenable to extension in order to handle preference semantics.

The task of creating preference semantics for our proposed computational framework may turn out to be a challenging one because of the need to provide for the existence of alternative points of view.

6 Current State and Future Work

At the time of writing of this paper, our PhD project is at the beginning of its second year. Currently, we are working on the formal description of our framework by employing argumentation dialogue frameworks based on situational calculus and dialogue games. At the same time, we are developing a Prolog-based proof of concept prototype to illustrate and validate the main definitions. The prototype uses a sample domain ontology about Programming Languages and takes as input Prolog-based definitions of dialogue moves (i.e. it assumes that the moves have been recognised). Once the framework is developed and tuned by using the prototype, we plan to deploy it in an existing educational semantic web system, e.g. OntoAIMS [3], to help learners make links between learning resources and become aware of different perspectives of content and ontologies.

Future work will include the completion of the formal description of the aforementioned frameworks and the creation of viewpoint discrepancy identification algorithms. It will also include the deployment of argument structures and relationships supporting the expression of different points of view. We finally aim to develop and test the architecture of the proposed computational framework illustrated in figure 1.

7 Expected Contribution

This PhD project proposes a dialectic approach for exploiting viewpoint discrepancies in interactive learning environments. The key characteristics of our approach are that: (a) viewpoints are composed of positions, relevant beliefs and supporting arguments; (b) incompleteness of or discrepancies between viewpoints are used as triggers for argumentative dialogue games; (c) viewpoints represent statements valid in particular contexts, which is explored during the interaction; (d) while discrepancies and similarities between viewpoints are explored, changes in viewpoints are not imposed; (e) viewpoints are accumulated in viewpoint stores and can be shown to a learner to promote domain awareness or to a human tutor to highlight problems with learning resources or existing ontologies. We expect that with the completion of this PhD project, we will contribute to knowledge, as follows:

We will demonstrate an application of argumentation dialogues and ontological reasoning for clarifying the context under which domain conceptualisations are formed. We will show how a pedagogical agent can overcome the closed domain limitation and can deal with an open domain for the tutor. The pedagogical agent we envisage will be able to enrich its knowledge and adopt or discuss new viewpoints. We will demonstrate new opportunities for tutoring and pedagogical systems that provide learning environments which employ common sense reasoning and are open to new knowledge.

Although argumentation is already applied in Collaborative problem solving systems, systems supporting conflict of opinion generally employ an 'off-the-shelf' debate theory e.g. which does not address educational objectives. We will demonstrate how a software agent aiming to use argumentation for learning will build its dialogue strategies around a clearly defined set of pedagogical objectives associated with dialogue games. Further, by employing a formalised approach we aim to provide a rigorous description of the agent so that its properties can be researched thoroughly and can be applied in different intelligent tutoring scenarios.

The software agent we propose will be able to update its knowledge via new trusted content ontologies on the web and will also be able to integrate different viewpoints expressed in learning objects. The reason why this is possible is because ontologies allow conceptual and terminological comparisons, they can be integrated with other ontologies and can be used to detect discrepancies automatically.

8 Acknolwedgement

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Sheaf-Theoretic Approach to Context Modeling

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Abstract. We outline a rigorous definition of contextuality in a frame of sheaf-theoretic formal semantics of some unspecified natural language, say for us English, French, German, Italian considered as a means of communication. Our approach provides a mathematical model of contextuality while rejecting the attempts to codify interpretative practice as a kind of calculus.

Introduction

According to Rastier (1996), there are two main theoretical preconceptions about human language: as a means of representation or as a means of communication. If the former involves in theoretic treatment some mental phenomena explained in the terms of cognition and mind, the latter deals with more observable phenomena, that is with messages in oral and written forms. In the present paper, we consider a natural language as a means of linguistic communication mainly in a written form. We consider the class of basic communicative units of a language as made up of texts, and so it differs from the class of all stand-alone sentences studied in traditional logical and grammatical theories. In the following, the only texts we consider are supposed to be written with good grace and intended for human understanding; we call them *admissible*.

1 Text and its Parts as Syntactic Concepts

A spoken utterance is a temporal series of sounds produced by a speaker using a human articulatory apparatus. When written, an acoustic signal is converted into a series of signs whose positions are linearly ordered following an adopted convention, that is from left to right within lines, and from top to bottom between them. Once a particular sign is taken as the initial, it allows to specify the position of the following signs by enumeration. From a mathematical point of view, the whole segment may be considered as a finite sequence when the last sign is specified. Thus a sentence is considered as a sequence of its words and a text as a sequence of its sentences. To exclude a possible misunderstanding, it seems to be useful to give some formal definitions. Recall that a *finite sequence* with terms in a set S is a function from a set $\{1, 2, \ldots, n\}$ to S for some natural number n. When a particular sequence is denoted as a series of certain elements of S, the element whose denotation occupies the i-th place from the left is understood as a value of the aforesaid function taken at i. So a sequence of real numbers is usually denoted as $(a_1, a_2, \ldots, a_n)$, where a_1 denotes the first number, a_2 denotes the second, and so on, a_n denotes the n-th number; usually it is written simply as (a_i). For exemple, $(8, 3, 1024, 19, 3)$ denotes a function, say f, such that $f(1) = 8, f(2) = 3, f(3) = 1024, f(4) = 19, f(5) = 3$. One may denotes this function as $(a_1, a_2, \ldots, a_5)$ or simply (a_i), where $a_1 = f(1), a_2 = f(2), \ldots, a_5 = f(5)$. Similarly for a function whose values are taken in a set of letters, say the set of all letters of the latin alphabet. In this case commas and brackets may be omitted, as for exemple in $ABBA$. Here $f(1) = A, f(2) = B, f(3) = B, f(4) = A$.

There are various different formalization of the concept of function in mathematics. In a classical set-theoretic formalisme (Kelly 1959), a function is identified with its *graph*. Formally, a function f is a class whose members are ordered pairs such that for each x, each y, each z, if $\langle x, y\rangle \in f$ and $\langle x, z\rangle \in f$, then $y = z$; that is all functions are single-valued. Intuitively, for an ordered pair $\langle x, y\rangle \in f$, a function is a "rule" that assigns the element y to the element x (y is the value of f for the argument x).

In the case of the sequence $ABBA$, the underlying function is the following set of ordered pairs $\{\langle 1, A\rangle, \langle 2, B\rangle, \langle 3, B\rangle, \langle 4, A\rangle\}$. The first coordinate (argument) is a place number, the value of a function at i-th place is a letter occurring where. Here, the arguments $1, 2, 3, 4$ indicate the order of letters reading. Similarly for the order of words reading in a sentence viewed as a sequence of words, and for the order of sentences reading in a text viewed as a sequence of sentences. From a linguistic point of view, essential is the *order type* of the ordered set of arguments $\{1, 2, 3, 4\}$ indexing the order of reading; any other ordered set order-isomorphic to $\{1, 2, 3, 4\}$ may be taken as a domain of the function represented by a sequence $ABBA$.

In calculus textbooks (see Grauert, Lieb (1970) for an example), one usually defines a subsequence of a given sequence as a sequence formed from the given sequence by deleting some of the elements without disturbing the relative positions of the remaining elements. The latter states that the positions of remaining elements are numbered by the induced order. Formally this means that a subsequence g of a given sequence f is defined as a subset $g \subset f$, and so g is a function whose domain is a subset of a domain of f.

In the linguistic situation, one may suppose that a considered text is typed on a paper band as if one has received it from the teletype output; any part of text may be distinguished from the rest by a color textmarker. In reading this particular distinguished fragment, we delete mentally the other sentences, but follow the induced order of remaining sentences. Important here is the order of their subsequent reading and not the concret index numbers of their occupied places. Nevertheless, their serial numbers may be easily identified by using this paper carrier of the text. Thus any part of a whole text is simply a subsequence of a full sequence.

In calculus textbooks, there exists also a slightly different definition of subsequence used in the case of infinite sequence. Namely, let $(a_i)_{i\in\mathbb{N}}$ be an infinite sequence of elements of a set S, that is a is a function $a\colon \mathbb{N} \to S$. If $k\colon \mathbb{N} \to \mathbb{N}$

is a strictly monotone function then $a \circ k \colon \mathbb{N} \to S$ is said to be a subsequence of a given sequence $(a_i)_{i\in\mathbb{N}}$, which is usually denoted as $(a_{i_k})_{k\in\mathbb{N}}$. As a kind of technical definition, this one is designed specially for the study of convergence of infinite sequences.

2 Basic Semantic Concepts

We distinguish the semantic notions *sense*, *meaning* and *reference*. The term *fragmentary meaning* of some fragment of a given text is accepted as the content grasped in some particular situation of reading guided by the reader's presuppositions and preferences in the interpretative process, which we denominate by the term *sense* or *mode of reading*.

Every reading is only an interpretation where the historicity of the reader and the historicity of the text are involved; thus in this acceptance, a *fragmentary meaning* is immanent not in a given fragment, but in an interpretative process of its reading. In this terminological acceptance, the reader grasps a *fragmentary meaning* in a particular interpretative process guided by some *mode of reading* or *sense* adopted in accordance with the particular attitude and based on the linguistic competence, which is rooted in the social practice of communication with others using the medium of language.

The understanding of meaning is based not only on the shared language, but principally on the shared experience as a common life-world and it deals so with the reality. According to Gadamer, this being-with-each-other is a general building principle both in life and in language. The understanding of a natural language text results from being together in a common world. This understanding as a presumed agreement on "what this fragment U wants to say" becomes for the reader its fragmentary meaning s. In this terminological acceptance, the meaning of an expression is the content that one grasps when one understands it; and this can be done regardless of the ontological status of its *reference*. The process of coming to some fragmentary meaning s of a fragment U may be thought of as an exercise of the human capacity of naming and understanding.

In our acceptance, the notion *sense* (or *mode of reading*) may be considered as a kind of semantic orientation in the interpretative process that relates to the totality of text or its fragment, sentence or its syntagma, and involves the reader's subjective premises that what is to be understood constitutes a meaningful whole. At the level of text, it may be *literal, historical, allegoric, moral, eschatological, psychoanalytical, naïve, common, Platonic, Leibnizian, Fregean, Kripkean*, etc. At the level of sentence, it may be *literal, metaphoric*, etc. At the level of word, it may be *literal* or *figurative*. In this acceptance, the term *sense* or *mode of reading* concerns the reader's interest in the subject matter of the text; it is a kind of questioning that allows a reader to enter into a dialogue with the author.

So our acceptance of the term *sense* is near to the exegetic concept of the four senses of the Sacred Scripture, whereas our usage of the term *fragmentary meaning* corresponds rather to the common usage of ordinary English words.

So in the formal analysis of text understanding, we distinguish the semantic notions *sense*, *meaning* and *reference*. Note that, following accepted terminology, we can read one and the same text in many different senses (moral, historical, etc.) to realize, in result, that we have grasped the different meanings. Likewise for a sentence or an expression. We would like to stress here the difference between this acceptance and the Fregean acceptance of *Sinn* as the "mode of presentation of reference" which is often illustrated by the famous example of "morning star" and "evening star". We consider it as an example of two different texts or expressions; each of them may be interpreted in many different *senses* or *modes of reading* and, following a chosen sense (mode of reading), we can grasp the different meanings of it.

3 Phonocentric Topology

3.1 Topology and Meaningfulness

When reading a text, the understanding is not postponed until the final sentence. So the text should have the meaningful parts and the meanings of these parts determine the meaning of the whole as it is postulated by the principle of the *hermeneutic circle*. The philological investigations are abound in examples of meaningful fragments quoted from the studied texts. Thus a meaningful part might be a subject of comment or discussion for being considered as worth interpretation. Certainly, not each subsequence of a given text is meaningful, but our acknowledgement that a given fragment is meaningful depends on some implicitly accepted *criterion of meaningfulness*. This criterion is not a matter of linguistic competence or cultural level of the reader but is accepted as taken for granted. Whether the criterion of meaningfulness is explicitly formulated as a certain "rule" or not, it is reasonable to consider the set of all meaningful parts of a given text X. This set may be thought of as a representation *in extensio* of an adopted criterion of meaningfulness, likewise a graph of a given function represents *in extensio* the "rule" it applies in order to transforme its "input" in its "output". Clearly the subset of all meaningful fragments of a given text X is a very small part of the set of all its subsets; for exemple, for a one page text of 40 sentences, the number 2^{40} of all its possibles parts is about trillion. But a formal study of the subset of all meaningful fragments allows to distinguish some their properties which are essential to any reasonable criterion of meaningfulness. We argue that in agreement with our intuition:

(i) *an arbitrary union of meaningful parts of an admissible text is meaningful;*
(ii) *a non-empty intersection of two meaningful parts of an admissible text is meaningful.*

The first item is a simple rephrasing of the hermeneutic cycle principle that prescribes to understand a whole (here, the union) by means of understanding of its parts. This principle states implicitly that the understanding of the whole should be arrived at whenever one has come to understandings of its parts. This formal property should be required of any reasonable criterion of meaningfulness.

The second item expresses the context-based mechanism of a natural language text understanding. The understanding of a (meaningful) fragment U implies that its sentences are interpreted as taken together in a single discourse where the whole U constitutes a larger possible context which affects the interpretation of each sentence. For a given sentence $x \in U$, this largest possible context (of U) is usually excessive and it is plausible that there should be in U some smaller meaningful neighborhood of x sufficient to grasp the same understanding of x. Since there are only finite number of such neighborhoods, there should exist the smallest one which supplies the context providing the same understanding of x as the whole U. This property seems to be essential for a fragment to be meaningful: to understand a fragment is to understand contextually all its sentences. Let now U and V be two meaningful subfragments with a non-empty intersection W. It is clear that each sentence x belongs to the intersection $U \cap V$ together with a smallest neighborhood providing the same understanding of x, as for $x \in U$ and for $x \in V$; hence W is also meaningful.

Since an admissible text X is supposed to be meaningful as a whole by the very definition, it remains to define formally the meaning of its empty part $\varnothing$ in order to provide X with some *topology* in a strict mathematical sense, where the set $\mathcal{O}(X)$ of all opens $U \subset X$ is nothing more as a set of all its meaningful parts (called further *fragments*).

Recall that a *topological space* is defined as a pair (X, τ), where X is a set, whose elements are called points, and τ is a family of subsets of X, which contains the empty set and the whole X, and which is closed under arbitrary unions and finite intersections. The set X is called the *space* of the *topology* τ, and the family τ is called a *topological structure* or just a topology on the space X; the subsets in τ are said to be *open*.

Any explicitly stated concept of meaning or criterion of meaningfulness allows to define some type of *semantic topology* on texts. Thus, for the class of scientific texts, it will be pertinent the criterion of *verifiability* or else, following another philosophical approach, the criterion of *falsifiability*; one may also adopt, following Einstein, some *operational* criterion of meaningfulness. Note that it is a difficult philosophical problem to elaborate some formal definition of meaningfulness. Essential, however, is the simple observation that any reasonable definition of meaning or criterion of meaningfulness gives rise to certain topology on the discourse domain.

This allows to interpret several tasks of discourse analysis in topological terms (Prosorov 2002, 2006a, 2006b). It seems also to be useful in matter of comparing different notions of meaning: we may pose that the notion τ_1 of meaning is *stronger* than another one, say τ_2, if the topology defined by τ_1 is stronger than the topology defined by τ_2, i.e., the identity map of underlying text gives rise to the continuous map

$$(X, \tau_1) \to (X, \tau_2)$$

of the topological spaces defined on the same text.

In the present talk, our analysis concerns only a domain of admissible texts in a natural language considered as a means of communication; we supposes that an admissible text is endowed with a semantic topology corresponding the less restrictive criterion of meaningfulness which may be thought of as an implicite formulation of the reader's linguistic competence. We call *phonocentric* the topology so defined.

These considerations may be repeated with slight modifications in order to define a *phonocentric* topology at the semantic level of sentence and even of word. Recall that we consider a sentence as a sequence of its words. In order to find the underlying phonocentric topology, we need to distinguish at the level of sentence its significant fragments or syntagmas being analogue to the meaningful parts at the level of text. In (2006a), we discuss how a phonocentric topology may be defined at the semantic level of sentence and even word.

So at each semantic level (text, sentence, word) of a given admissible text, we distinguish its *primitive elements* which are the points of a corresponding topological space considered to be the *whole* at this level. The passage from one semantic level to another immediately superior consists in gluing of the whole space into a point of the higher level space.

In the present talk, our analysis concernes only a domain of admissible texts endowed with a phonocentric topology.

3.2 Separation Axioms

Clearly, not all the parts of an admissible text are meaningful, as for example a part made up of all $100n$-th sentences of a sufficiently large text; hence the phonocentric topology isn't *discrete*. On the other hand, there are certainly the proper meaningful parts in an admissible text; for example it seems to be usually meaningful a part made up of the initial paragraph. Hence the phonocentric topology isn't *coarse*.

The natural process of reading supposes that understanding of any sentence x of the text X should be achieved on the basis of the text's part already read, because the interpretation cannot be postponed, although it may be made more precise and corrected in further reading and rereading. This is a fundamental feature of a competent reader's behavior described by Rastier (1995) as follows:

> Alors que le régime herméneutique des langages formels est celui du suspens, car leur interprétation peut se déployer après le calcul, les textes ne connaissent jamais le suspens de l'interprétation. Elle est compulsive et incoercible. Par exemple, les mots inconnus, les noms propres, voire les non-mots sont interprétés, validement ou non, peu importe.

Thus for every pair of different sentences x, y of a text X, there is an open (that is meaningful) part U of X, which contains one of them (to be read first in the natural order $\leq$ of sentences reading) but doesn't contain the other. Whence a phonocentric topology at the semantic level of text should satisfy the *separation axiom* T_0 of Kolmogoroff. Similarly, a phonocentric topology at the semantic level of sentence should also satisfy the *separation axiom* T_0.

A topological space is said to satisfy the *separation axiom* T_1 of Fréchet if every singleton subset is closed. Since a topological space provided by an admissible text should be finite, any T_1-topology on an admissible text should be *discret.* If we suppose that some semantic topology at the level of text satisfies the axiom T_1 then all textual parts should be meaningful. In the case of non-trivial underlying concept of meaningfulness, it may happen only for rare examples of short textes in a few sentences. Likewise for the *separation axiom* T_2 of Hausdorff.

On the contrary, as already argued above, a phonocentric topology at each semantic level of an admissible text should satisfy the *separation axiom* T_0. It may be taken as the characteristic property in a possible axiomatic definition of phonocentric topology.

It is a difficult combinatory problem to enumerate all the distinct T_0-topologies on a finite set up to homeomorphism. Probably not all of them may be represented as a phonocentric topology on some admissible text. However the study of the representable ones may be conceived as a *formal textual syntax.*

3.3 Phonocentric Topology and Specialization Order

An admissible text X gives rise to a finite space, hence an arbitrary intersection of its open sets is open and so it is an *Alexandroff space.*

For a sentence $x \in X$, we define U_x to be the intersection of all the meaningful parts that contain x, that is the smallest open neighborhood of x. We define the *specialization* relation $\preceq$ on X by setting $x \preceq y$ if and only if $x \in U_y$ or, equivalently, $U_x \subset U_y$ (Erné 1991). Note that for all $x, y \in X$, $x \preceq y$ implies $x \leq y$, where $\leq$ denotes the natural linear order of reading.

Proposition. *The set of all open sets of the kind U_x is a basis of a phonocentric topology on X. Moreover, it is the unique minimal basis of a phonocentric topology. The phonocentric topology on an admissible text defines a partial order structure $\preceq$ on it by means of specialization; the initial phonocentric topology can be recovered from this partial order $\preceq$ in a unique way.*

This is a linguistic variant of a well-known general result concerning the relations between T_0-topologies and partial orders on a finite set. That is, the category (in a strict mathematical sense) of finite topological T_0-spaces and continuous maps is isomorphic to the category of finite partially ordered sets (*posets*) and monotone maps. Namely, given a finite poset $(X, \leqslant)$, one defines a T_0-topology on X by means of the basis of τ constituted of all *low sets* $\{z \mid z \leqslant x\}$. Thus one obtains a functor $L\colon (X, \leqslant) \to (X, \tau)$ acting identically on the underlying set maps, which is a functor from the category of posets and monotone maps to the category of topological spaces and continuous maps.

Conversely, the specialization functor $Q\colon (X, \tau) \to (X, \preceq)$, assigning to each finite topological space (X, τ) a poset $(X, \preceq)$ with the specialization order $\preceq$ and acting identically on the underlying set maps, is a functor from the category of finite topological T_0-spaces and continuous maps to the category of posets and monotone maps. From a mathematical point of view, the study of one of these two categories is logically equivalent to the study of another.

In (Prosorov 2006a), we show how these considerations may be repeated with slight modifications in order to define a *phonocentric* topology at each semantic level of a given admissible text. At each semantic level (text, sentence, word), we distinguish its *primitive elements* which are the points of a corresponding topological space considered to be the *whole* at this level. The passage from one semantic level to another immediately superior consists in gluing of the whole space into a point of the higher level space.

Thus at each semantic level of a given admissible text, there exist two natural order structures:

(i) *the specialization order* $x \preceq y$ *defined by applying the specialization functor* Q *to the natural phonocentric topology of a considered semantic level;*
(ii) *the linear order* $x \leq y$ *of ordinary text reading.*

On the other hand, at each semantic level of a given admissible text, there exist two topological structures:

(i) *the natural phonocentric topology of a considered semantic level;*
(ii) *the topology defined by applying the functor* L *to the linear order* $x \leq y$ *of ordinary text reading.*

Note that, in these notations at the semantic level of text, the relation $x \preceq y$ implies the relation $x \leq y$ for all $x, y \in X$. Thus the identity map of underlying sets gives rise to the continuous map $L(X, \preceq) \to L(X, \leq)$ of corresponding topological spaces. So the necessary linearization during the writing process results in weakening of the phonocentric topology by the transition from $L(X, \preceq)$ to $L(X, \leq)$. The process of interpretation consists in a backward recovering of the phonocentric topology on a given text.

3.4 Graphical Representation of a Finite Poset

There exists a simple intuitive tool called Hasse diagram for the graphical representation of a finite poset which allows to visualize the corresponding topology.

Definition. Let $(X, \preceq)$ be a finite poset. The *cover relation* $\prec$ on X is defined by setting $x \prec y$ if and only if $x \preceq y$ and there exists no element $z \in X$ such that $x \preceq z \preceq y$ ($x \prec y$ is read as "*y covers x*"). For a finite poset $(X, \preceq)$, its Hasse diagram is defined as the graph whose vertices are the elements of X and whose edges are those pairs $\{x, y\}$ for which $x \prec y$.

The usage of some kind of Hasse diagram under the name of *Leitfaden* is widely spread in the mathematical texts. So, in *Differencial forms in algebraic topology* by R. Bott and L. W. Tu, there is a Leitfaden reproduced in Fig. 1. Indeed, the authors presuppose here the linear reading of paragraphs 1-6, 8-11, 13-16 and 20-22, which may be drawn explicitly. But one may go further and do the next step in "splitting" the above diagram in order to draw the diagram whose vertices are all the sentences; or one can do it directly, i.e. by means of analytical reading find all the basic sets U_x and then draw the Hasse diagram of a corresponding poset. Certainly, the authors has some clear representation of this kind during the writing process. Anyhow, the representations of this kind appear implicitly during the reading process at each semantic level. Thus for a given admissible

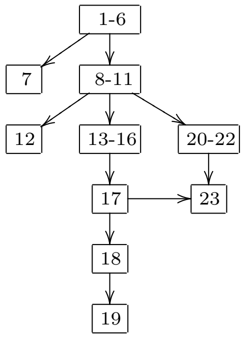

Fig. 1. Example of Leitfaden.

text, we can find, in a constructive manner, its phonocentric topology at each semantic level and then draw the Hasse diagram of the corresponding poset. Its study is equal to the study of a corresponding notions of topology and order and may be thought of as a kind of *formal syntax*.

4 Sheaves of Fragmentary Meanings

Let X be an admissible text, and let $\mathcal{F}$ be an adopted sense of reading. For each open $U \subset X$, we collect all the fragmentary meanings of U in the set $\mathcal{F}(U)$. Thus we are given a map $U \mapsto \mathcal{F}(U)$ defined on the set $\mathcal{O}(X)$ of all opens $U \subset X$. The precept of the hermeneutic circle "to understand a part in accordance with the understanding of the whole" defines a family of maps $\mathrm{res}_{V,\,U} \colon \mathcal{F}(V) \to \mathcal{F}(U)$, where $U \subset V$, with the properties of 1° identity preserving: $\mathrm{res}_{V,\,V} = \mathrm{id}_{\mathcal{F}(V)}$ and 2° transitivity: $\mathrm{res}_{V,\,U} \circ \mathrm{res}_{W,\,V} = \mathrm{res}_{W,\,U}$ for all nested opens $U \subset V \subset W$. Mathematically, the data $(\mathcal{F}(V), \mathrm{res}_{V,\,U})_{V,U \in \mathcal{O}(X)}$ is a *presheaf* of sets over topological space X.

4.1 Identity criterion for fragmentary meanings

Following Quine (1977), there is no entity without identity; otherwise, it were impossible to consider the fragmentary meanings to be well-defined objects susceptible to set-theoretic operations and quantifications with them. So we need some notion of identity between fragmentary meanings which are accepted technically as the content grasped during the reading process. We formalize a process of reading of a fragment U as its covering $U = \bigcup_{j \in J} U_j$ by some family of subfragments $(U_j)_{j \in J}$ already read. In this model, we suppose that the reading of each fragment U_j is realized as a distinct physical act which results in its interpretation. In reading practice, the understanding of "what this particular fragment U_j wants to say" is usually thought of as a grasping of its meaning - some entity, say s_j, of a sort of label somehow associated with the fragment U_j. If a person reads each U_j as meaningful text taken separately, the family of fragments (U_j) gives rise to some family of independent meanings (s_j).

But when (U_j) are taken together as a covering of a single text U, their understandings should be coherent. The obvious constraint concernes their non-void pairwise overlappings. If one grasps the meanings of U_i and U_j independently, there are no constraints for the understanding of $U_i \cap U_j$. But taking U_i and U_j as a single text $U_i \cup U_j$, makes the reader go back and re-interpret their overlapping, in order to get their local coherence. To summing up, it seems to be quite adequate to our linguistic intuition that two fragmentary meanings s, t of U should be considered as identical globally on U if and only if they are identical locally, i.e. on every U_j such that $U = \bigcup_{j \in J} U_j$. So, an explicit *criterion of identity* between fragmentary meanings is defined by the following:

Claim S (Separability). *Let X be an admissible text, and let U be a fragment of X. Suppose that s, t are two fragmentary meanings of U and there is an open covering $U = \bigcup_{j \in J} U_j$ such that $\mathrm{res}_{U, U_j}(s) = \mathrm{res}_{U, U_j}(t)$ for all U_j. Then $s = t$.*

This definition determines an effective procedure to decide whether two given meanings s, t of one and the same fragment $U \subset X$ are equal. One may resume this definition in saying that two fragmentary meanings are considered as equal globally if and only if they are equal locally.

4.2 Compositionality of Fragmentary Meanings

The hermeneutic circle prescribes "to understand the whole by means of understandings of its parts", so a presheaf of fragmentary meanings should satisfy:

Claim C (Compositionality). *Let X be an admissible text, and let U be a fragment of X. Suppose that $U = \bigcup_{j \in J} U_j$ is an open covering of U and there is a family $(s_j)_{j \in J}$ of fragmentary meanings, $s_j \in \mathcal{F}(U_j)$ for all U_j, such that $\mathrm{res}_{U_i, U_i \cap U_j}(s_i) = \mathrm{res}_{U_j, U_i \cap U_j}(s_j)$. Then there exists some meaning s of the whole fragment U such that $\mathrm{res}_{U, U_j}(s) = s_j$ for all U_j.*

In mathematics, a presheaf satisfying both claims (S) and (C) is said to be a *sheaf* by the very definition, which motivates the following:

Frege's Generalized Compositionality Principle. *A presheaf of fragmentary meanings $\mathcal{F}$ naturally attached to any sense (mode of reading) of an admissible text X is really a sheaf; the sections $s \in \mathcal{F}(U)$ over a fragment $U \subset X$ are the fragmentary meanings of U; the sections $s \in \mathcal{F}(X)$ (global sections) are the meanings of the text X as a whole.*

The claim (S) implies the meaning s, whose existence is claimed by (C), to be unique as such.

4.3 Category of Schleiermacher

We suppose that any part which is meaningful in one sense (mode of reading) should remain meaningful under the passage to some another sense in the ordinary process of reading. A *morphism* of sheaves $\phi\colon \mathcal{F} \mapsto \mathcal{F}'$ is a family of maps $\phi(V)\colon \mathcal{F}(V) \to \mathcal{F}'(V)$ that represents a transfer from the understanding in the sense $\mathcal{F}$ (e.g. historical) to the understanding in the sense $\mathcal{F}'$ (e.g. moral) which is compatible with the restriction maps; in other words, it is to say that the diagram of mappings

$$\begin{tikzcd}
\mathcal{F}(V) \arrow[r, "\phi(V)"] \arrow[d, "\mathrm{res}_{V,\,U}"'] & \mathcal{G}(V) \arrow[d, "\mathrm{res}'_{V,\,U}"] \\
\mathcal{F}(U) \arrow[r, "\phi(U)"'] & \mathcal{G}(U)
\end{tikzcd}$$

commutes for all fragments $U \subset V$ of X.

Thus, given an admissible text X, the data of all sheaves of fragmentary meanings together with all its morphisms constitutes a *category* in a strict mathematical sense, we call *category of Schleiermacher*; it supplies a formal framework for the part-whole structure in the natural language text interpretation formulated by Schleiermacher as the principle of *hermeneutic circle*.

5 Contextuality

So far, we have considered the fragmentary meanings of open sets of a topological space naturally attached to any sense (mode of reading) of an admissible text. It may happen that a particular point (sentence) $x \in X$ constitutes a one-element set $\{x\}$ which is open, and so the set of its fragmentary meanings $\mathcal{F}(\{x\})$ have been yet defined. Certainly, not all points, that is one-point sets, are open in a phonocentric topology. We define now the meanings of all points (sentences).

Let U, V be two open neighborhoods of a sentence x and let $\mathcal{F}$ be an adopted sense. Two fragmentary meanings $s \in \mathcal{F}(U)$, $t \in \mathcal{F}(V)$ are said to induce the same contextual meaning at $x \in U \cap V$ if there exists some open neighborhood W of x, such that $W \subset U \cap V$ and $\mathrm{res}_{U,\,W}(s) = \mathrm{res}_{V,\,W}(t) \in \mathcal{F}(W)$. The identity of fragmentary meanings mentioned here is supposed to be established by using the identity criterion (S).

This relation "induce the same contextual meaning at x" is clearly an equivalence relation; any equivalence class of fragmentary meanings agreeing in some open neighborhood of a sentence x is said to be a *contextual meaning* of x. The set of all equivalence classes is called a *stalk* of $\mathcal{F}$ at x and denoted by $\mathcal{F}_x$. The equivalence class determined in $\mathcal{F}_x$ by a fragmentary meaning $s \in \mathcal{F}(U)$ is called a *germ of s at x* and denoted by $\mathrm{germ}_x s$. Paraphrasing Frege (1884), we say: "Never ask for the meaning of a sentence in isolation, but only in the context of some fragment of a text". To be precise, we give the following formal definition that describes really a particular construction of the *inductive limit*:

Frege's Generalized Contextuality Principle. *Let $\mathcal{F}$ be an adopted sense (mode of reading) of a fragment U of an admissible text X; for a sentence $x \in U \subset X$, its contextual meaning is defined as* $\mathrm{germ}_x(s)$ *i.e. a* germ *at x of some fragmentary meaning $s \in \mathcal{F}(U)$; the set $\mathcal{F}_x$ of contextual meanings of a sentence $x \in X$ is defined as the inductive limit $\mathcal{F}_x = \varinjlim(\mathcal{F}(U), \mathrm{res}_{V,\,U})_{U,V \in \mathcal{O}(x)}$, where $\mathcal{O}(x)$ is a set of all open neighborhoods of x.*

Note that for any open one-point set $\{x\}$, we may identify $\mathcal{F}_x = \mathcal{F}(\{x\})$.

The notion of *contextual meaning* of a point may be defined similarly at the semantic level of sentence and even a word.

To illustrate the notion of contextual meaning at the level of text with a simple example, let us consider a sentence $x =$ "John is a philosopher". Anybody surely understands what it means in a conversation, as for example "John is a philosopher (for he lets reason govern his life)", or "John is a philosopher (for he studies philosophy at Harvard)", etc. On the contrary, to make understandable what this sentence x means when it is written in some text, the author ought to write some meaningful fragment U containing x. The smallest such a neighborhood U_x depends on the particular author's communicative intention and, in general, this U_x cannot be reduced to x. Hence, the grasped contextual meaning of x corresponds to the equivalence class of some fragmentary meaning $s \in \mathcal{F}(U)$. So, a contextual meaning of x should be identified with a $\mathrm{germ}_x(s)$ of some fragmentary meaning $s \in \mathcal{F}(U)$. For any other sentence $z \in U_x$ such that $z \neq x$, we have $U_z \neq U_x$, and hence the contextual meaning of z is defined by one of the fragmentary meanings of U_z, not of U_x, despite of the fact that z lies in U_x. So the process of the reader's understanding of a fragmentary meaning s of U may be thought of as a consecutive choice of only one contextual meaning $\mathrm{germ}_x(s)$ for each sentence x of U.

5.1 Contextuality in Categorical Termes

For the coproduct $F = \bigsqcup_{x \in X} \mathcal{F}_x$, we define now a map $p\colon F \to X$ as $p(\mathrm{germ}_x s) = x$ which we call a *projection*. Every fragmentary meaning $s \in \mathcal{F}(U)$ determines a genuine function $\dot{s}\colon x \mapsto \mathrm{germ}_x s$ to be well-defined on U; for each $x \in U$, its value $\dot{s}(x)$ is taken in $\mathcal{F}_x$.

This gives rise to functional representation $\eta(U)\colon s \mapsto \dot{s}$ for all fragmentary meanings $s \in \mathcal{F}(U)$ which clarifies their nature and allows to establish an *inductive theory of meaning* (Prosorov 2003, 2005b) describing how the interpretative process develops in time.

We define the topology on F by taking as a basis of open sets all the image sets $\dot{s}(U) \subset F$. Given a fragment $U \subset X$, a continuous function $t\colon U \to F$ such that $t(x) \in p^{-1}(x)$ for all $x \in U$ is called a *cross-section*. For any cross-section $t\colon U \to F$, the projection p has the obvious property $p(t(x)) = x$ for all $x \in U$. The topology defined on F makes p and every cross-section of the kind of $\dot{s}$ to be continuous. So we have defined two topological spaces F, X and a continuous map $p\colon F \to X$. In topology, this data (F, p) is called a *bundle over the base* *space* X. A *morphism* of bundles from $p\colon F \to X$ to $q\colon G \to X$ is a continuous map $h\colon F \to G$ such that $q \circ h = p$.

We have so defined a category of bundles over X. A bundle (F, p) over X is called *étale* if $p\colon F \to X$ is a local homeomorphism. Étale bundles and their morphisms constitute a full subcategory in the category of bundles over X. It is immediately seen that a bundle of contextual meanings $(\bigsqcup_{x\in X} \mathcal{F}_x, p)$ constructed as above from a given sheaf $\mathcal{F}$ of fragmentary meanings is étale. Thus, for an admissible text X, we have defined the category $\mathbf{Context}(X)$ of étale bundles of contextual meanings over X as a framework for the generalized contextuality principle at the level of text.

The similar definition may be formulated at each semantic level. This one formulated at the level of sentence renders Frege's classic contextuality principle. As soon as the semantic level is fixed, the definition of a contextual meaning for a point x of a corresponding topological space X is given as $\mathrm{germ}_x s$, where s is some fragmentary meaning defined on some neighborhood U of x.

5.2 Some Applications of the Developed Theory

For a given admissible text X, we have defined two categories formalizing the interpretative process: the Schleiermacher category $\mathbf{Schl}(X)$ of *sheaves* of fragmentary meanings and the category $\mathbf{Context}(X)$ of *étale bundles* of contextual meanings. In (Prosorov 2003, 2005a) these categories are related to each other using a fundamental categorical conception of adjoint pair of functors which, in our linguistic situation, become a pair of well-known *germ-functor* $\Lambda\colon \mathbf{Schl}(X) \to \mathbf{Context}(X)$ and *section-functor* $\Gamma\colon \mathbf{Context}(X) \to \mathbf{Schl}(X)$.

The fundamental theorem of topology states that the section-functor Γ and the germ-functor Λ establish a *dual adjunction* between the category of presheaves and the category of bundles (over the same topological space); this dual adjunction restricts to a *dual equivalence* of categories (or *duality*) between corresponding full subcategories of sheaves and of étale bundles (Lambek, Scott 1986 and Mac Lane, Moerdijk 1992). In the linguistic situation, this important result yields the following:

Theorem (Frege duality). *The generalized compositionality and contextuality principles are formulated in terms of categories that are in natural duality*

$$\mathbf{Schl}(X) \underset{\Gamma}{\overset{\Lambda}{\rightleftarrows}} \mathbf{Context}(X)$$

established by the section-functor Γ and the germ-functor Λ, which are the pair of adjoint functors.

The proof of theorem follows the same general technical principles which are used in the proofs of many well-known classic dualities such as Stone, Gelfand-Naimark, and Pontrjagin-van Kampen, to name a few.

Stated in sheaf-theoretic termes, Frege duality theorem gives a simple solution to an old problem concerning the delicate relations between Frege's Compositionality and Contextuality Principles, in revealing that the acception of one of them implies the acception of the other. A comprehensive examination of this problem and its history is presented in (Janssen 2001).

Another application is based on the functional representation of fragmentary meanings at each semantic level that permits to establish an *inductive theory of meaning* (Prosorov 2004, 2005b) describing how runs in time the process of text understanding. For more details, we refer the reader to our works (2004, 2005a).

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Contextual bilattices

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Bilattices, introduced by Matthew Ginsberg [1] as a uniform framework for inference in Artificial Intelligence, are algebraic structures that have proved fruitful in many fields. However, they have never been applied to contextual reasoning so far. My aim here is to sketch one such possible application.

The basic idea is to order contexts in a space of "truth values" forming a bilattice, that is a lattice with two partial orders. In order to do this we employ a bilattice construction developed in [1], where it was used to handle the "justifications" of a *Truth Maintenance System*, that is sets of premises used for derivations. My proposal is that the same formal machinery may be also applied to sets of formulas representing not premises in the usual logical sense but contexts.

In cognitive processes, the notion of context may be defined as a part of the epistemic state of an agent, i.e. as a set of implicit assumptions. These assumptions enable us to assign a reference to indexical expressions such as "this", "here", "now" etc., and so to determine the truth value of the sentences involving them. The simplest way to formalize this is to identify contexts with subsets of the knowledge base, i.e. sets of formulas.

Let $C_1, \ldots, C_n$ be sets of formulas intended to represent contexts. To each sentence p we may associate the set $C^+ = \{C_1, \ldots, C_n\}$ of all contexts in which p holds. We assume each C_i to be a set of sentences, possibly cointaining contextual "axioms" such as "Speaker = ...", " Time = ..." etc., that logically imply p. We shall denote this writing $v(p) = [C^+]$. This is the basic idea that provides a link with the multi-valued setting of bilattices, that is the idea to treat contexts as truth values.

If we want to handle inconsistent beliefs, we may also consider the set C^- of all contexts in which $\neg p$ holds, without requiring that C^+ and C^- be disjoint, so that we may have some context in which both p and $\neg p$ hold. Therefore, instead of writing only $v(p) = [C^+]$, meaning that the value of p is given by the contexts in which p holds, we shall write $v(p) = [C^+, C^-]$, meaning that the value of p is given by the contexts in which p holds together with the contexts in which $\neg p$ holds.

Now we define an order relation on these "truth values". We may order contexts in an intuitive way by set inclusion. For instance, $C_2 \subseteq C_1$ means that C_2 is more general than C_1, since C_2 requires fewer assumptions than C_1. (The most general context is the empty context, corresponding to sentences that are completely context-independent.) This intuition may be applied to sets of contexts as follows. Given two sets of contexts $C = \{C_1, \ldots, C_m\}$ and $D = \{D_1, \ldots, D_n\}$, we set $C \leq D$ iff for all $C_i \in C$ there is some $D_j \in D$ such that

$D_j \subseteq C_i$. That is, for every context in C, there is some context in D which is more general: so if we know that p holds in D and q holds in C, we can conclude that p is less context-dependent than q.

Of course this is not the only possible way to define an order on (sets of) contexts. For instance we might consider the logical (instead of just the set inclusion) relationship between the propositions representing contexts.

Suppose we have two contexts C and D such that $C \nsubseteq D$ and $D \nsubseteq C$ but $D \subseteq \mathrm{th}\,(C)$, that is $C \vDash p$ for each sentence $p \in D$. Since D is contained in the logical consequences of C, from a deductive point of view we might expect to have $C \leq D$. According to this intuition we could replace the previous definition with the more general: $C \leq D$ iff $D \subseteq \mathrm{th}\,(C)$.

However, we shall not employ this definition here because it would not allow to construct a lattice of contexts in an effective way. In fact, in order to determine if $C \leq D$ we would have to check if $D \subseteq \mathrm{th}\,(C)$, which is obviously a complex task from a computational point of view.

Instead, we prefer to adopt the simpler set inclusion definition, delaying the difficult part of the job to a later stage of the inference process. This means that if p holds in C and q holds in D, with $D \subseteq \mathrm{th}\,(C)$, this relation will not be reflected in the values assigned to p and q by the initial valuation v until we have applied some suitable closure operator (such as the one introduced in [1]). That is, we will not have $v\,(p) \leq v\,(q)$ with respect to our lattice order, but we expect to have $\mathrm{cl}\,(v\,(p)) \leq \mathrm{cl}\,(v\,(q))$.

Adopting the set inclusion order relation we are now able to define a lattice of sets of contexts. Let F be the set of all formulas in the knowledge base and $P\,(F)$ its power set, that is the set of all possible contexts. If we denote the set of all sets of contexts by $L = P\,(P\,(F))$, then the structure $\langle L, \leq \rangle$ is the lattice of sets of contexts.

Now, in order to consider inconsistent beliefs, we employ two copies of L, one for the contexts in which a sentence p holds and the other for those in which $\neg p$ holds. In this way we construct a bilattice, i.e. a set equipped with two orders each one forming a lattice. The elements of a bilattice are intended to represent truth values ordered according to the degree of truth ($\leq_t$) and the degree of knowledge ($\leq_k$). Intuitively, $v\,(p) \leq_t v\,(q)$ means that the agent has stronger evidence for the truth of q than for the truth of p and weaker evidence for the falsity of q than for that of p, while $v\,(p) \leq_k v\,(q)$ means that the agent has stronger evidence for *both* the truth and falsity of q than for the truth and falsity of p (thus allowing for inconsistency).

Thus the "contextual bilattice" is $\langle L \times L, \leq_t, \leq_k \rangle$, the underlying set being formed by the ordered couples $[C^+, C^-]$ of elements of the lattice of sets of contexts. The two order relations may be defined as follows. For any two elements $[C^+, C^-]$, $[D^+, D^-] \in L \times L$:

$$\begin{array}{lcl} \left[C^+, C^-\right] \leq_t \left[D^+, D^-\right] & \text{iff} & C^+ \leq D^+ \quad \text{and} \quad C^- \geq D^- \\ \left[C^+, C^-\right] \leq_k \left[D^+, D^-\right] & \text{iff} & C^+ \leq D^+ \quad \text{and} \quad C^- \leq D^- \end{array}$$

It can be verified that our definition reflects the previous considerations on the two orderings. The logical connectives may then be defined as lattice operators, for instance conjunction and disjunction correspond respectively to the greatest lower bound and least upper bound with respect to the truth ordering. Negation is defined in a straightforward way as a function swapping the "truth" and "falsity degree", so that we have $\neg [C^+, C^-] = [C^-, C^+]$. In a similar way other connectives (classical or not) may be defined, such as those corresponding to the greatest lower bound and least upper bound with respect to the knowledge ordering.

The next step would be to construct a suitable inference mechanism for "contextual bilattices". This has already been done for the general case (see for instance [1] and [2]), but it remains to show that such mechanisms may be successfully applied to contextual reasoning. As a preliminary result, we may see an application to our setting of the closure operator defined by Ginsberg [1].

Consider a set A of assumptions. We define an initial valuation v as follows. For each sentence p:

$$v(p) = \begin{cases} [(\{p\}), ()] & \text{if } p \in A \\ [(), ()] & \text{otherwise.} \end{cases}$$

In this way we are labelling each sentence in A as self-justified, i.e associated with a context consisting only of itself. Then we apply to v the closure operator cl, which is meant to be the multi-valued analogue of the deductive closure operator of classical logic. It is possible to show that, for each $\{p_1, \ldots, p_n, q\} \subseteq A$, we have:

$$\mathrm{cl}(v(q)) \geq_c [(\{p_1, \ldots, p_n\}), ()] \quad \text{iff} \quad p_1, \ldots, p_n \vDash q$$
$$\mathrm{cl}(v(q)) \geq_c [(), (\{p_1, \ldots, p_n\})] \quad \text{iff} \quad p_1, \ldots, p_n \vDash \neg q$$

So we see that, whenever a sentence q (or its negation) holds in some context $C = \{p_1, \ldots, p_n\}$, this information is punctually reflected in the value assigned to q once we have applied the closure operator.

Another issue would be to incorporate inference rules that are *local* in the sense of [3], that is relative to a given context. I believe these may be interesting topics for future investigation.

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Local Model Semantics, Categories, and External Representation: Towards a Model for Geo-historical Context

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Abstract. Perspectives within social interaction situations are often shaped by geo-historical contexts derived from knowledge of indirectly experienceable phenomena such as geographic scale entities and past events that are communicated through external representations such as maps and historical accounts. Although geo-historical context is important for proving meaning to collaborative situations, no formal approach for modeling geo-historical context exists. This paper will provide a preliminary analysis of how select aspects of Local Model Semantics (LMS), used in conjunction with geographic and historic categories, can be used to theoretically inform the formal modeling of geo-historical context and how external representations affect geographical and historical categories. A brief case-study example will be given to show how geo-visual tools theoretically informed by LMS, geographical and historical categories, and external representation can support the development of geo-historical context from heterogeneous sources in a collaborative setting.

Keywords: Local Model Semantics, Categories, Geography, History, External Representation

1 Introduction

Situations of social interaction, such as collaborative problem solving, are inherently shaped by context. The context of the situation shapes and provides meaning to situations of social interaction by surrounding those situations with varying knowledge elements and varying degrees of knowledge detail, creating unique perspectives for those involved in the situation [3]. For certain social interaction situations, perspectives are developed from knowledge of phenomena that can not be directly experienced because of scale (i.e beyond the immediate field of vision) or time (such as historical knowledge of a phenomena derived from past events that can never be revisited) [10, 13].

The examination and representation of phenomena that can not be directly experienced is a cornerstone of Geographic inquiry. For example, a common use of a map is to provide geo-spatial context for a situation, such a traveling. When a map is coupled with a historic account, artifact, or temporal information on the map, situations can then be contextualized from a *geo-historical* perspective. A geo-historical context allows a situation to be understood in relation to past events, as well as interactions and relationships of locations within those events that have operated across any number of space/time scales and thus can not be directly experienced. For example, in the domain of crisis management, preparedness and mitigation activities taken by disaster management officials in a hurricane-prone region in anticipation of a large hurricane hitting the region might create scenarios based on past events that specifically occurred in that location (for example, a locality was struck the previous year by a hurricane, or a major hurricane twenty years ago), or use spatially or temporally analogous facts (such a small city in one state that was not effected by a recent hurricane comparing its vulnerability and potential destruction to similar small city in another states that was effected by a recent hurricane)[12].

Although geo-historical context is of great importance for providing meaning to collaborative situations, no approach for formally modeling geo-historical context exists. The benefits of developing an approach to formally modeling geo-historical context is two fold. The first is that the processes of developing a model can lead to further insight into the nature, meaning, and representation of space/time phenomena by examining theoretical issues of geographical and historical knowledge conceptualization, categorization and external representation. Second, by understanding the theoretical and conceptual dimensions of geo-historical context, knowledge representation and reasoning systems designed to represent geo-historical context can be more effective for application domains such as collaborative problem solving activities and situation assessment in crisis management.

The focus of this paper will be to examine aspects of the theoretical issues of geographical and historical knowledge categorization and representation as means toward developing a formal model of geo-historical context. Specifically, a review will be made of Local Model Semantics (LMS) [7, 8] and a preliminary analysis made of how select aspects of LMS, in conjunction with geographic and historic categories, can be used to theoretically inform the development of geo-historical context. Next, a discussion will be given on how external representation affects geographical and historical categories. A brief case-study example will then be given to show how geo-visual tools theoretically informed by LMS, geographical and historical categories, and external representation can be designed to support the development of geo-historical context in a collaborative setting and what effect, if any, external representations have on categorizations, knowledge and reasoning within collaborative problem-solving. The paper will conclude with a summary and areas for future research.

2 Local Model Semantics

Local Model Semantics (LMS) is a semantic model for reasoning with contexts. LMS takes an approach that assumes localized, goal directed, domain specific theories of the world form the basis of what an agent knows, and that the sum of an agents knowledge is developed by composing local theories through rules that connect the theories into a comprehensive, yet partial representation of the world [4, 7]. Reasoning is local to a single given context that is seen as a partial state of the world derived from an individual perspective, drawn from a subset of knowledge, and relevant to the context or problem at hand [16].

Ghidini and Giunchiglia [7:229] outline two principles underlying the intuitions for the use of context in LMS:

Principle 1 (of Locality). Reasoning uses only part of what is potentially available (e.g., what is known, the available inference procedures). The part being used while reasoning is what (is called) context (of reasoning);

Principle 2 (of Compatibility). There is compatibility among the kinds of reasoning performed in different contexts.

Locality can be seen as the set of facts an individual uses to develop a representation for reasoning about the world [16]. Compatibility refers to the possible mutually influential relationships between local reasoning where similar perspectives and contexts can describe the same piece of the world but with different details [4].

The following is a brief technical discussion of the notions local models, models and context in Local Model Semantics as discussed in Ghidini and Giunchiglia [7:226-230] and [8]

L_i - a family of formal languages defined over a set of indexes I, L_i is a representation language that describes what is true in a context

$\overline{M_i}$ is the class of all models or interpretations of L_i so that each L_i in $\{ L_i \}$ is interpreted in its own, potentially different structure.

$m \in \overline{M_i}$ is a *local model* of L_i

Local models are paired into single structures through *compatibility sequences and relations*. Compatibly sequences pair local models that are mutually compatible and consistent with the situation being described. These pairings create *models* derived from sets of mutually compatible sequences of local models.

A compatibility sequence c for L_i is a sequence $c = < c_0, c_1, \ldots c_i \ldots >$

Where for each $i \in I$, c_i is a subset of $\overline{M_i}$ (or the model and interpretations of L_i)

A compatibility relation C (for a given language L_i) is a set C of compatibility sequences c

A model (for L_i) is defined as a compatibility relation with at least one sequence and does not contain a sequence of empty sets. These are conditions formally defined as

(1)$C \neq \emptyset$;
(2)$< \emptyset, \emptyset, \emptyset \ldots \emptyset > \notin C$;

Given a model $C < c_0, c_{1,}... c_{i...}>$, context is any c_i allowed in C within a particular compatibility sequence. A context consists of a set of models that exactly captures facts which are locally true within the constraints posed by local models of other contexts in the same compatibility sequence, as allowed by a given compatibility relation. Context is thus formed from a set of models and is partial object.

3 Categories and External Representation

One theoretical approach that could be used in parallel with LMS as a starting point for developing representation languages, local models, models and contexts relevant to geo-historical contexts derived from multi-scale phenomena is basic-level category theory [14]. In particular, the use of geographic categories [9, 17] and historical categories [20] can be used to understand geo-historical context at various scale and detail dependant levels.

Basic-level geographic categories (country, region, state, etc.) capture the hierarchical nature of how the world is categorized, often based on spatially contained regions [11]. The historic category state of experience, or where past things are present or can be remembered allows for a formal structuring of past events. When basic-level geographic categories and the historic category state of experience are combined, they can form the basis for defining local languages (L_i). Subordinate geographic categories (United States, Pennsylvania, etc) and specific past events can from the basis for local models (M_i) that are interpretations of L_i that can in turn form compatibility sequences.

The following is a discussion of how the geographic-historic situation "Waynesboro Bourough, located in Franklin County, Pennsylvania had a flood in 1980" could be modeled with LMS. In this example, three of the four propositional languages (L_s,L_c,L_b) are based, respectively, on basic geographic categories (county, borough, state). Each of these languages would utilize propositional constants derived from a set of toponyms (that are in fact subordinate level geographic categories) that fall within the administrative hierarchy of the category and/or are constrained topologically based on the situation being modeled (see [6] for a discussion of topological relationships relevant to geographic phenomena). Topological constraints in fact serve as a form of compatibility between local models as the sets of facts in one local model will structurally affect and/or influence other local models [8]. For example, P_s = {*Alabama, Alaska, Arizona...Pennsylvania..n*} would define US states that in turn would effect P_c = {*Adams, Allegheny, Armstrong, Beaver…n*} which would only be those counties within the state of Pennsylvania. P_b would be only those boroughs within a selected county that is within the state of Pennsylvania.

The propositional language for state of experience (L_h) could be based on an inventory of past disaster events[1]. Facts within $L_{h,}$ for this example, would be derived from a compatibility relationship defined as events that occurred within the geographic region of the situation (in this case, Pennsylvania). Subordinate level

[1] For example, an inventory such as that found at http://www.fema.gov/news/disasters_state.fema?id=42

categories (as defined by toponyms and events) serve as compatibility sequences within local models.

A compatibility relationship is then formed through a set of compatibility sequences subject to constraints (such as a borough must be in a county which must be in a state) needed to represent the situation. A model of the languages being used to describe the situation is then formed from the compatibility relationship.

Visually, this situation, modeled with LMS, might appear like Figure 1.

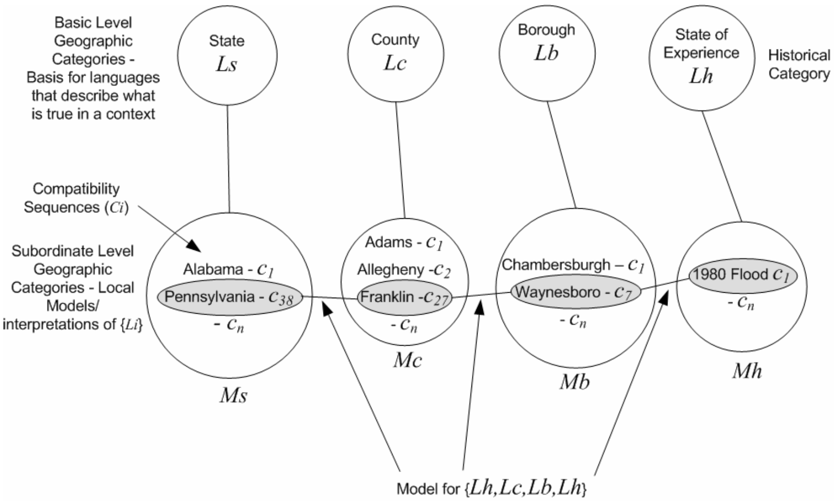

Figure 1: Modeling a Geographic-Historical Situation with LMS

For practical application and use, the previously discussed approach to modeling a geo-historical situation will need to rely on external, visual representations for sense-making and reasoning. External, visual representation can serve as one form of external cognition than can structure or restructure a given situation and the geo-historic categories used in that situation. Knowledge subsets and local context models are derived from reality through external representations and reflect localized effects that range any where from geographic data availability to implicit ontologies, or a persons world view on how they conceptualize a given domain or geographic space (Figure 2).

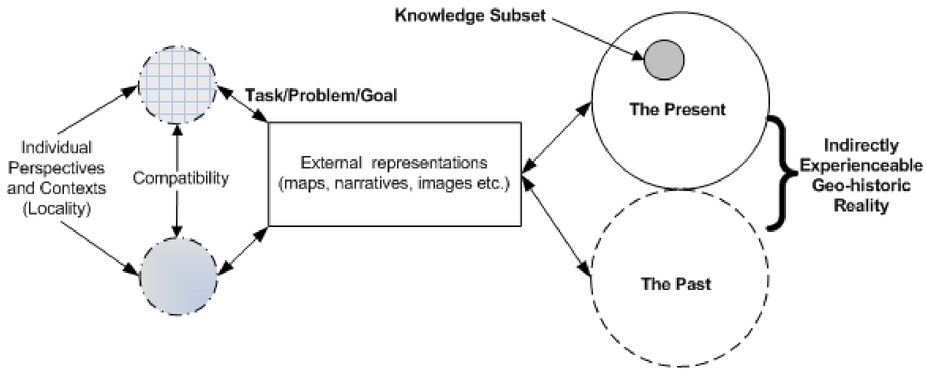

Figure 2: Knowledge subsets derived from reality through external representation that reflect localized effects; dashed lines represent individual perspectives/contexts drawn from subsets of knowledge of reality.

Structuring or restructuring a situation or the perspective on a situation through external representation may affect compatibility relationships between local models as reasoning about the situation maybe modified or influenced. For example, reasoning with a temporal/historical phenomena through a time line view versus a textual narrative or graphical constraining such as visually emphasizing one particular data source over another with modification to figure-ground relationships in order to draw attention to the source [15, 21].

3 Case Study

Ideally, collaborative development of geo-historical context from heterogeneous data sources can embrace the diversity of meaning, interpretations and perspectives on places and events contained in heterogeneous information sources and seek to find meaningful, compatibile relationships between local contexts of the collaborators. Furthermore, variation in geographical and historical detail contained within individual information sources can be retained and not abstracted away (for example, ensuring that a category of Central Pennsylvania is not abstracted to Pennsylvania). Retaining heterogeneity may be critical for broader contextualization of situations that reflect varying perspectives and changes in opinions [5]. For example, two news media outlets covering the same story may have varying degrees of geographic detail about a story; the local news outlet where the event discussed in the story occurred may have much more detail than a national outlet reporting the story.

From a human Geography perspective, it may be argued that relative, localized approaches to developing and understanding geo-historical context are ideal as these relative approaches embrace the richness, diversity, complexity, and interrelationships found within an "ecology of place" where understanding of place emerges from the interlacing of relationships and not from preset descriptive categories and essentialist approaches that see the world in an objective, conformist manner [1, 18].

The following is a hypothetical case study of how the basic concepts of Locality and Compatibility from LMS and geo-historical categories can inform how geo-historical context can be developed through external, visual representations. This case study uses an online prototype collaborative tool called the Context Discovery Application (CDA) that allows collaborators to develop geo-historical context from heterogeneous data sources such as news stories and shared geospatial data [19].

In this example, two officials from adjoining counties in the gulf coast region of the United States are examining ongoing relief efforts to hurricane Katrina using the CDA. In LMS terms, since both collaborators share have a common geographic area (the counties share a common border), they will have compatibility in their reasoning, but each will have different locality as a result of implicit ontologies that create differing local contexts based on different levels of detail available (such geo-spatial datasets and jurisdictions), needed or perceived.

In this example, the first hypothetical user (Brian, from Harrison County, Mississippi) has a local model of context that is derived from the basic-level geographic category of town, and subordinate categories of local streets within that town that form compatibility sequences as visually represented in the streets web map service (WMS[2]) layer (Figure 3).

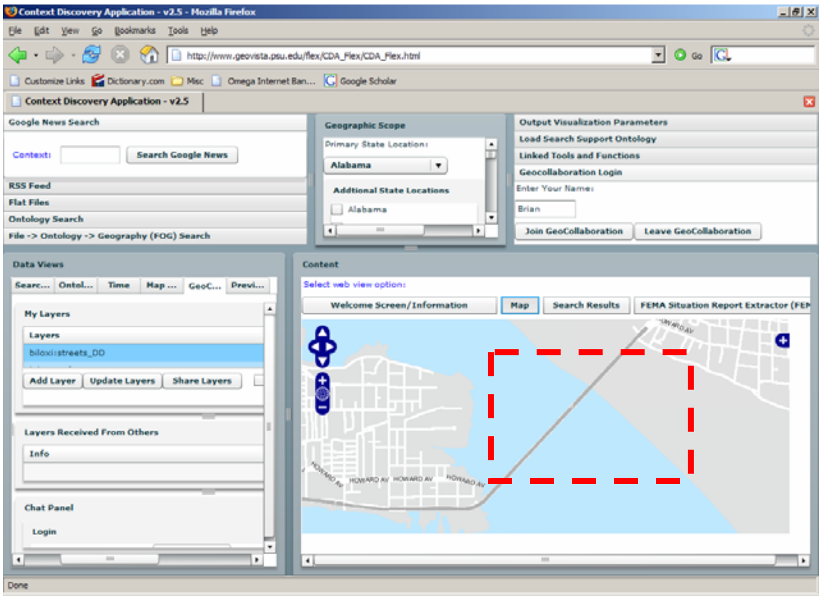

Figure 3: Visual representation of a local model (Brian). The dashed-line box represents the approximate common geographic areas between Brian and Donna.

The second hypothetical user (Donna, from Jackson County, Mississippi) has a local model of context that is derived from the basic geographic category of county and subordinate categories of streets only from that county at the county level (i.e. no local streets) (Figure 4).

[2] http://www.opengeospatial.org/standards/wms

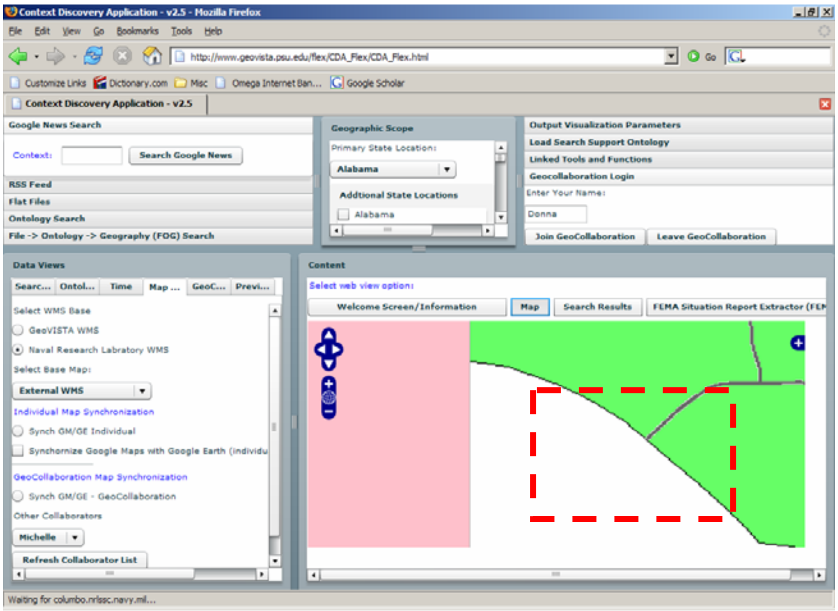

Figure 4: Visual representation of a local model (Donna). The solid area (pink) on the left is the area of Brian's local model, and is the limit of Donna's available data. The dashed-line box represents the approximate common geographic areas between Brian and Donna.

Because the local model of Donna is developed from visual representations that effect geographic categories Donna uses to reason with the local model, the level of detail and possible compatibility sequences within Donna's local model(s), in this case, is less than that of Brian since Donna has less visual representation available because of lack of data.

In Figures 3 and 4, the dashed-line boxes figuratively represent one possible form of geographic compatibility between Brian and Donna's reasoning. For example, the presence of a bridge in this area represents an object both users may need to reason with in shared problem solving., The bridge is likely to be part of the local reasoning of both users that will mutually influence, constrain and shape each users individual localized reasoning and possibly make their individual localized reasoning agree [8].

Using the CDA's search capabilities, Brian queries for news stories related to Harrison county Mississippi and Katrina. The news stories develop a local historical model for Brian as he can review recent past events related to recovery efforts (Figure 5).

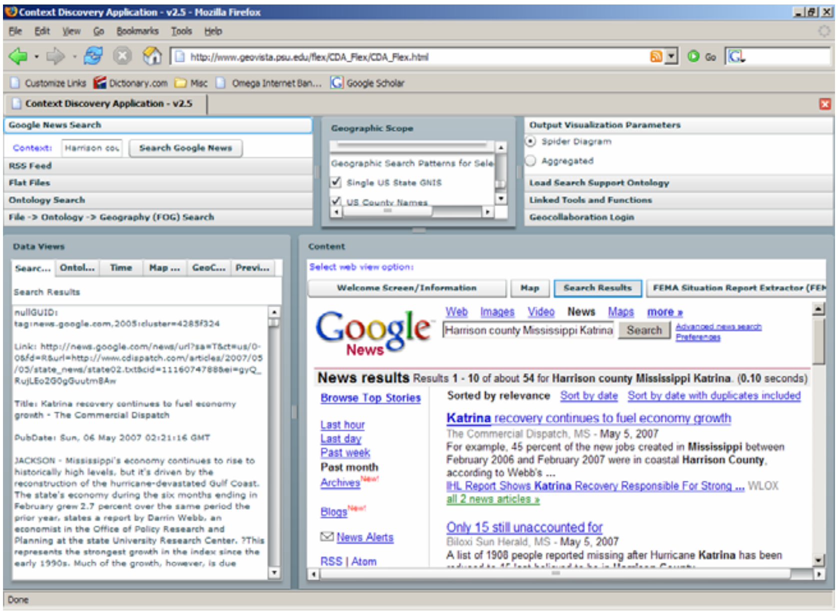

Figure 5: News stories related to 'Harrison county Mississippi Katrina' queried by Brian

Also using the CDA's search capabilities, Donna queries for news stories related to Jackson county Mississippi and Katrina. Like Brian, the returned news stories develop a local historical model for Donna as she can also review recent past events related to recovery efforts (Figure 6). The terms "Mississippi" and "Katrina" act as a compatibly relation between Donna and Brian as these terms will constrain and influence what information they will mutually view, and thus locally reason with.

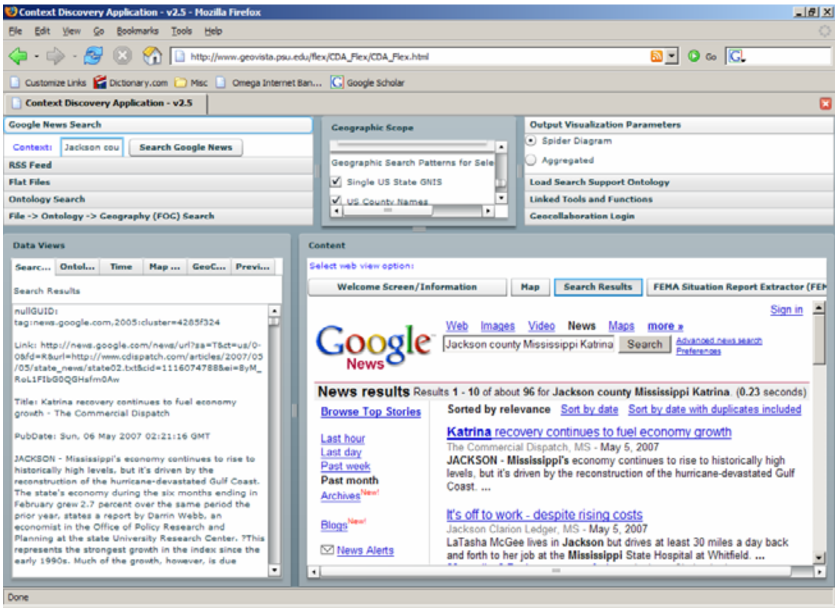

Figure 6: News stories related to 'Jackson county Mississippi Katrina' queried by Donna

Using a real time chat tool, both collaborators note the news story about Katrina recovery fueling economic growth. The story provides commonality for both collaborators, and represents a shift in context that requires more factual detail (such as increased geo-spatial data representation to understand geographical dimensions of the economic growth such as the effects on neighborhoods or civil infrastructure) so that shared problem solving and investigation into the situation can continue. Using the geocollaborative tools of the CDA, Brian has his local streets layer drawn on Donna's map, thereby adding more detail to Donna's local contextual model through visual representation (Figure 7).

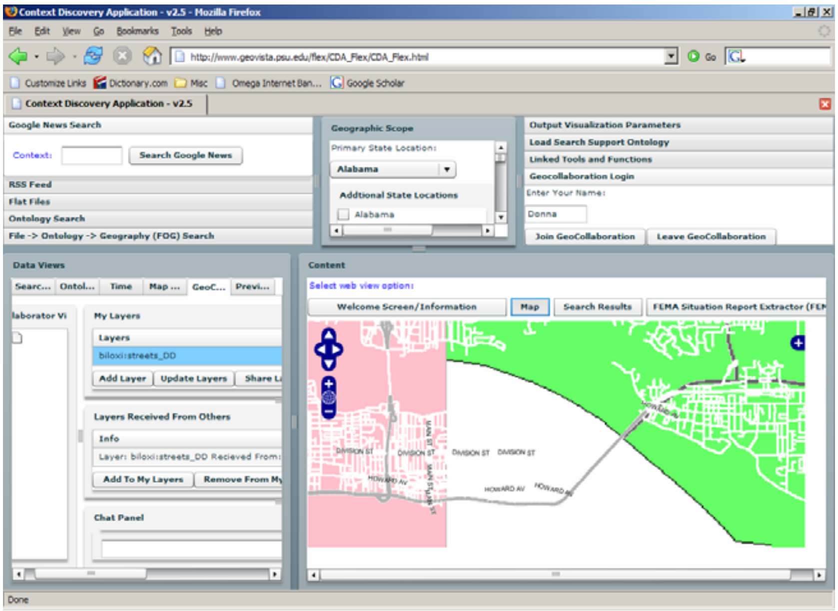

Figure 7: Level of detail in Donna's local model increased by the addition of visual representations from Brian.

3 Conclusions and Future Work

LMS and basic-level categories show promise for providing a theoretical and conceptual basis for informing the design of visual representations and virtual collaboration environments that model and represent geo-historical context. Future work on refined models and formal language definitions of specific geographic and historical categories and the effects that ad-hoc categories, or categories that do not have a regular, correlational environmental structure or are not well established in memory [2] may have on contextual models can lead to enhanced knowledge representation and reasoning and external representation procedures that can be used to develop geo-historical context from heterogeneous data sources.

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A Domain-Independent Approach for Contextual Elements Management

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Abstract. The development of context-sensitive systems entails more work in comparison to traditional systems: in the former, one must care for context-related tasks, such as the acquisition, processing, storage, manipulation and presentation of contextual elements. Context management aims to provide solutions to separate context related tasks from applications' business features. In this paper we present our proposal for the problem of context management through a generic, domain-independent context manager, named CEManTIKA. In order to abstract away domain specificities CEManTIKA introduces an approach to context modelling, named *Context-Oriented Model* (COM). COM separates the context modelling in three layers where an abstract and high level layer defines the generic and specific context related concepts.

Keywords: Context Management, Generic Context Model, Context-Sensitive System, Context Representation

1 Introduction

Context can be defined as the collection of relevant conditions and surrounding influences that make a situation unique and comprehensible [1]. The term *Contextual Element* (CE) refers to pieces of data, information or knowledge that can be used to define the context [2]. Context-sensitive systems are those that understand and use contextual elements to provide relevant services and/or information to the users or to other applications during the execution of some task.

Although trivial and intuitive in human to human interactions, modelling and manipulating context in human to computer interactions is not a trivial task. A context-sensitive system may take into account context-related tasks such as: to specify the CEs needed in the application domain; to build components to acquire the CEs; to create aggregation and reasoning modules that enable it to process the acquired CEs according to the application needs; to identify the relevant CEs according to the user's current situation; and to use the CE to provide for the application adaptability. Besides, the usage and management of contextual elements, generally, is not the main feature in a computer system, but an optional, secondary functionality, so these tasks become an overhead for the system developer.

Most context-sensitive systems do not take into account requirements such as modularity, reusability or interoperability [3] and implement the context manipulation in a proprietary way to attend to particular needs of each system. Context management aims at providing solutions to separate the context-related tasks from applications' business. This enables the systems to reuse solutions and to share contextual elements easing the complex development of these systems.

Although there are already in the literature some proposals for context management (e.g. [4-8]), this is still an open topic for research since it comprises several unsolved challenges, such as: (1) support to multiple domains, and not only the Ubiquitous Computing domain, since existent context managers are intended to support the particularities of this domain and do not consider the usage by other domains; (2) the implementation of a generic context model that enables the sharing and processing of contextual elements, and that abstracts away particularities of an application domain; and (3) the ability to enable the incremental definition and acquisition of contextual elements, since context is dynamic and changes over time.

This paper presents our thesis proposal whose main objective is to model and develop a generic contextual elements management system which we called CEManTIKA (*Contextual Elements Management Through Incremental Knowledge Acquisition*). We defined the following goals for this system: (1) to define a generic context model that enables the contextual elements processing and reusability by different applications in distinctive domains; (2) to provide models and specifications that enables the management of a contextual elements base and the incremental acquisition of contextual elements; and (3) to enable the identification and instantiation of contextual elements sets relevant according to a given task.

The expected contributions of this work are: the specification of the main components of the CEManTIKA system, and the definition of a generic context representation model to support the context management inter-domains, called COM (*Context-Oriented Model*).

Next sections discuss the concepts beyond context management (Section 2), related works (Section 3), the COM modelling approach (Section 4), an overview of the CEManTIKA proposal (Section 5), some implementation decisions and preliminary results (Section 6), and final considerations and future work (Section 7).

2 Context Management

Context Management (CM) can be defined in terms of the subtasks it comprises, as:

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CM = acquisition + processing + dissemination (of CEs)
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CE Acquisition refers to the process of monitoring and gathering contextual elements from physical or virtual environments. This is done in three ways: (1) by the *user*, which informs them directly since not all elements can be automatically acquired; (2) by *physical* or *logical sensors* that monitor the environment the user is in, providing elements such as location and time (physical) or users' actions (logical); (3) gathered from the *group memory* that provides historical elements about the group interactions, or from *application models*, that include profiles, preferences, user, task, group models and so on. To help understand the acquired elements, *domain ontologies* can and must be used.

CE Processing is related to the problem of how to obtain useful CEs from the set of heterogeneous elements gathered from multiple sources. Functionalities of reasoning and analysis should be available to infer new high level elements from existing low level ones [9] (e.g. transforming contextual data into contextual information). Current inference engines can provide reasoning support, as is the case of the Jena framework [10], which uses description logics and first order logics to perform inferences. However, considering its nature, it is crucial to consider uncertainty when reasoning about context. So, more sophisticated reasoning techniques can also be used, such as Bayesian networks, neural networks, fuzzy logic, case-based reasoning and machine learning.

CE Dissemination entails the delivery of contextual elements acquired and processed by the context manager to applications or context-aware services. There are three different ways of delivering context: the application can directly query the context manager; the application can subscribe to the manager as interested in specific contextual elements and every time that element changes the application is notified; or, the manager keeps contextual elements up-to-date in a context channel that applications can listen to gather them.

These three main tasks are just conceptual, and they don't necessarily map to components in an implementation. A context manager is a computer system that implements the functionalities to enable the management of CEs, including the definition of models and languages to describe them, infrastructure to detect, update and query them on a shared repository, and mechanisms to allow the reasoning over existing CEs [2]. The context manager is an intermediate layer between context sources and context consumers, and it aims at providing contextual elements acquired from these sources to the interested consumers (the context-sensitive systems).

These main tasks may be provided directly by any context-sensitive system. However, a context manager separates the context-related tasks from the application business. This allows reducing the complexity of building context-sensitive systems, by transferring tasks related to CE management to a middle layer. Thus, a context manager brings four added advantages: *reusability*, the solution for each context management task can be done in a generic way and be reused by several applications; *sharing*, applications can share CE acquired from different and heterogeneous context sources; *context source independence*, applications are developed independently from the underlying contextual source; *ease of use*, application developers can focus on their business model and leave details of context management to the manager implementation.

The context management tasks must be constructed under a well developed context model that enables the representation of the contextual elements. As stated in [11] “A well done approach to represent and recovery context is a key factor in context-sensitive systems”. Thus, in order to be effective, the context manager must take into account some aspects such as the separation of the context model and the application domain model and the maintenance of a sharable context model that enables the communication between different components or systems.

3 Related Works

The proposals for context management that appear in the literature are associated to toolkits [4], frameworks [5], middlewares [8], engines [6] and specifications [7]. They propose their view over the three main context-related tasks and what differentiates one another is the way they propose to implement each task.

The main difference between our proposal and theirs are:

(i) Domain independence: they are mainly related to the domain of ubiquitous computing and for this reason they manage the contextual elements in a very particular way, according to the specificities of this domain. We propose a context manager whose context model enable that the core system could be reused in different domains by different applications;

(ii) Incremental Acquisition: they consider as contextual elements those that can be automatically achieved by physical and logical sensors, and define a priori a specific set of contextual elements that will be consider by the system, in a static way (e.g. location, identity, devices and activities); for us, this way of managing contextual elements is incompatible with the requirement of being generic and reusable.

Different approaches for context modelling are being experimented, such as key-value pairs [5], markup schemas [12], object-oriented models [13], ontologies [14;15] and topic maps [16]. Ontologies appears as a very promising and different ontologies are being proposed in the literature to model contextual elements related to specific domains, such as Ubiquitous Computing [17;18], Collaborative Systems [14], Geographical Information Systems [15], Music Resources [19], and others. Other ontologies are proposed as generic models reusable in different domains [20]. We could observe that these several ontologies have in common the fact that they try to delimit the contextual elements that should be considered in a domain. In this light they specify which contextual elements must be related to the 5W+1H questions, that is who (person), where (location), when (time), what (activity or event), how (state) and why (motivation).

Another approach for context modelling was proposed by Bucur et al. [21]. They combine the generality of ontologies with the complexity inspired by object oriented models, modelling two ontologies: a domain ontology and another ontology that is the description of the context attributes managed by the system, relating the context attributes with the domain concepts.

CEManTIKA differs from other approaches in the way it models the context and, consequently, the way of processing and managing it. The manager defines the procedures and infrastructure to manipulate CEs independently from a specific domain, without limiting them to a static and pre-defined set of CEs. Applications in different domains are supposed to be able to use the manager infrastructure in their development. To achieve this objective we propose a modelling approach (the *Context-Oriented Model*) that separates in different layers the general concepts related to context management from the domain specificities. Thus, CEManTIKA functionalities are implemented according to the general concepts and each domain instantiates the concepts according to their own particularities.

4 The COM Approach for Context Modeling

In human or service interactions, it is always desirable that each involved agent shares the same interpretation of the exchanged data. With the advancing of context-sensitive computing, the need for formal context models (which are well structured and enable context usage and sharing) is increasing. In human or service interactions, it is always desirable that each involved actor make compatible their interpretation of existing facts. One challenge in developing context-sensitive systems is the definition of how to represent context in a way that its usage could be done in a more efficient and appropriate way. Determining a context model needs to take into account things such as interoperability, extensibility, sharing and reusability.

Existing modelling proposals (e.g. [20;22]) are based on pre-defined and limited sets of contextual information, in general related to a specific domain, or that can be acquired through sensors. They establish a static and pre-defined set of entities and model the context directly as static attributes associated to these entities. Since context is a very subtle concept and has an infinite dimension, it is impractical to think about context management in a totally generic way without defining and limiting the scope of what will be characterized. Thus, a generic and reusable context model cannot be accomplished by establishing *a priori* a limited set of contextual elements related to a specific problem.

To develop our model we based our understanding about context as stated in the proposal of Brézillon and Pomerol [23]. They say that context is always related to a focus. Focus means an objective or a step in a task, a problem solving, or a decision making. The focus enables to separate knowledge that is relevant or that is not relevant to determine the context. The Contextual Knowledge (CK) is the known relevant part, while the External Knowledge (EK) is the unknown or irrelevant part in the context. The Proceduralized Context (PC) is the knowledge effectively used in the focus to support the task at hand; it is composed by a subset of the CK that is assembled, organized and instantiated to address the focus, along with the rationale that was used by the execution of inference rules to achieve the instantiated CK.

In this light, we propose the COM (*Context-Oriented Model*) approach. It divides the context modelling in three layers (Fig. 1): the *upper layer*, which characterizes the generic context management related concepts and can be qualified as a "meta-model" since it is used for creating individual models; the *middle layer* that defines the domain-specific context-related concepts in accordance with the upper layer; and the *lower layer*, which represents the instantiation of the domain concepts according to a specific application, incrementally acquired during the system usage.

We use the following hypothesis under this layer division: if we define the context specific concepts in a high level domain-independent layer, than these concepts can be managed in a generic manner, without worrying about the domain particularities. So, the mechanics of the context manager will be applied over the upper layer concepts and a compatible context-sensitive system must model the application specific concepts as instantiation of these upper concepts.

COM defines five <u>main concepts</u>: *Entity*, *Contextual Element*, *Focus*, *Rule* and *Action*; and three <u>derived concepts</u>: *CEF-Set*, *RF-Set* and *Proceduralized Context*. The main concepts must be instantiated by the application/domain analyst while the derived concepts are built by CEManTIKA based on the main concepts and guided by the focus. A brief description of each concept is done in the following and more details can be found in [24].

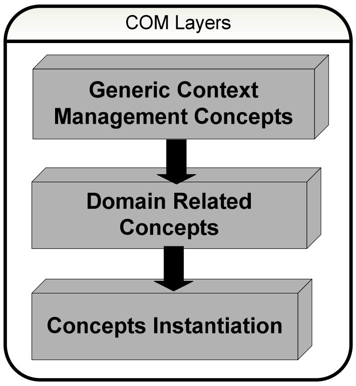

Fig. 1. Interaction between the three layers in the COM model [24]

- *Entity*: anything in the real world that is relevant to describe the domain (e.g. Artist, Release, Track in the Music Domain). An entity is characterized by one or more Contextual Elements;
- *Contextual Element*: identifies the atomic part of a context (being data, information or knowledge) and is used to characterize entities. For example, for the entity Track some CE include: *intention* (the way the music was meant to be played or used); *stimulus* (something that has caused the music to be created); *style* (indicate the main genre the music is related to). A CE may be composed by one or more entities, meaning that an entity is related to the CE. For example, the CE *commission* is associated to the entity Artist and is uses the entity Track to indicate that the artiste was paid for composing that piece of music;
- *Rule*: represent the rules associated to the CEs, necessary to produce contextual information from contextual data and also to support the building of the Proceduralized Context in the focus. Each rule has one or more conditions and returns one action. The conditions is represented by instances of type Contextual Element and the returned action is an instance of the class Action;
- *Action*: indicates what a context-sensitive system is supposed to trigger when a rule is activated; thus, the rules are specified according to defined actions;
- *Focus*: a central concept in COM model, since the context is always related to a focus. It is an objective to be achieved, such as a task in a problem solving or a step in a decision making, and it is used to identify clear points of time and space that the context is all about. The focus allows the context manager to determine what CEs should be used and instantiated, since it determines the relevancy of a CE in a specific situation;
- *CEF-Set*: is a collection of CEs that are relevant and must be instantiated in a focus. It is dynamically generated and will be continually rebuild when a new focus arrives. An CEF-Set related to a focus *f* (*CEF-SET(f)*) is comprised by a set of tuples (*c, v*) such that *c* is a Contextual Element, *v* is a value for *c*, being another Contextual Element or a literal (e.g. string, integer or date), and *c* has an association of relevancy with the focus *f*;

- *RF-Set*: determines the relevant *rules*, over all the pre-defined rules, that should be activated in the focus. The definition *RF-Set (f)* indicates that an RF-Set in a focus *f* is formed by a set of tuples (*r, a*) such that *r* is a Rule, *a* is an Action, *a* is a result of the execution of the rule *r*, and *r* has an association is related to the focus *f*;
- *Proceduralized Context*: contains the CEs that should effectively be used to support the current focus, and the rationale that has enabled the context manager to identify these CEs. It is constructed based on the contextual elements in the CEF-Set and the selected set of inference rules (the RF-Set). The PC is composed by an explanation related to the processing of the instantiation of the inference rules with the elements in the CEF-Set as conditions and the returned actions. Thus, the definition *PC(f)* states that the PC in a focus *f* is formed by a set of tuples [(*c, v*), (*r, a*)] such that (*c,v*) belongs to the CEF-Set, (*r*, *a*) exists in the RF-Set, *c* is a condition for *r*, and the execution of *r* with the tuple (*c*, *v*) return the action *a*.

Our modelling approach is based on the general idea that comprises paradigms as the object-oriented model or the aspect-oriented model. These modelling techniques define the main structure that enables the building of a computer system that fits each paradigm. If we are going to develop an object-oriented system our world must be represented according to *classes*, *properties*, *relationships* and *objects*. When modelling an aspect-oriented system, the world is modeled in terms of *aspects*, *join points*, *advices* and *pointcuts*. So, for us, when modelling a context-sensitive system we must think in terms of *entities*, *contextual elements*, *foci*, *rules* and *proceduralized contexts*.

An example of instantiating the main concepts in a music domain is illustrated in Fig. 2 showing the interaction between the three layers presented in Fig. 1. For the sake of space we describe only few aspects of each concept. In the example, were defined the entities *Artist*, *Band*, *Release*, *Track* and *Instrument*. The entity Artist is characterized by the CEs *locationOfOrigin* and *musicalStyle* (e.g. *Samba*, *Rock* or *Classic*). A Band is a specialization of Artist and thus it inherits the CEs definition. The entity Release identifies the musical oeuvres created by the artists. It is characterized by the CEs: *musicalStyle* and *date* (the date the release was divulged). The entity Track identifies a musical composition and is characterized by the CEs *musicalStyle* and *playedWith* (meaning instruments that are intended to be used to play the music). The entity Instrument indicates instances of musical instruments (e.g. *drums*, *piano* or *guitar*).

The example presents two foci: *Recommend Artist*, whose objective is to identify artists that could interest a given user, and *Choose Tracks for Location* to indicate if a track is appropriated to be played in a given location. The first focus uses the CEs *locationOfOrigin* and *date*, and the rule *newReleaseRule*, indicating if an artist has a new release. The second focus uses the CEs *locationOfOrigin*, *musicalStyle* and *playedWith*, and the rules *forChurchRule* and *IsSacredRule*, which is used to indicate if a Track is appropriate to be played in a church.

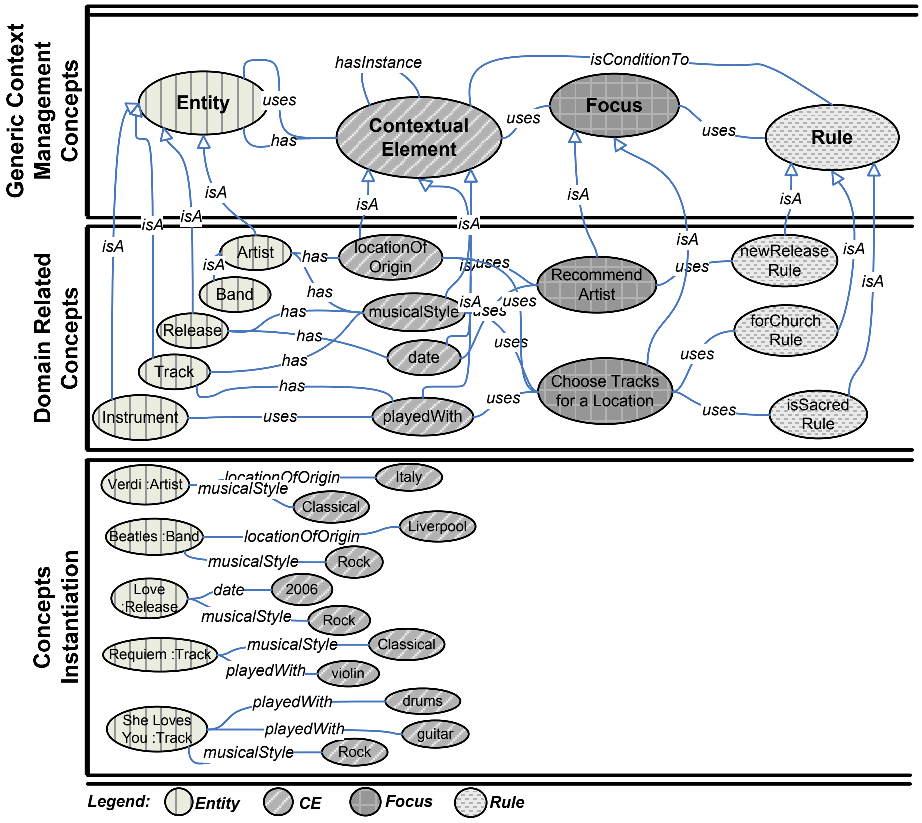

Fig. 2. Instantiation of COM main concepts in a Music Domain

5 Context Management in CEManTIKA

CEManTIKA (*Contextual Elements Management Through Incremental Knowledge Acquisition*) is a contextual elements management system which aims to support the management of contextual elements in a generic domain-independent way. CEManTIKA is based on two main processes: (1) the CE Identification and CEB Construction, which comprises the representation of the CEs in a domain and the acquisition of CEs from different context sources; and (2) the PC Building and PCB Maintenance. These processes are based on the model COM, described in the previous section.

CEManTIKA manages the different focus in the domain and, for a given focus, it identifies which CE Sets must be considered and instantiated to support the task at hand (the CEF Set). A Proceduralized Context Base (PCB) maintains historical cases of the CEF Set built and their respective focus. The historical CEF Sets stored in the PCB aid the identification of the relevant CEs in other focus.

An overview of the CEManTIKA architecture is presented in Fig. 3. The components are located in two different hosts: (1) *the context-aware system host*, where the context-sensitive system that uses the manager is running; (2) *the CEManTIKA server host* that maintains the core components and the repositories (CEB and PCB). The context sources and consumers (components in light gray) are the interaction points between the context-sensitive system and CEManTIKA.

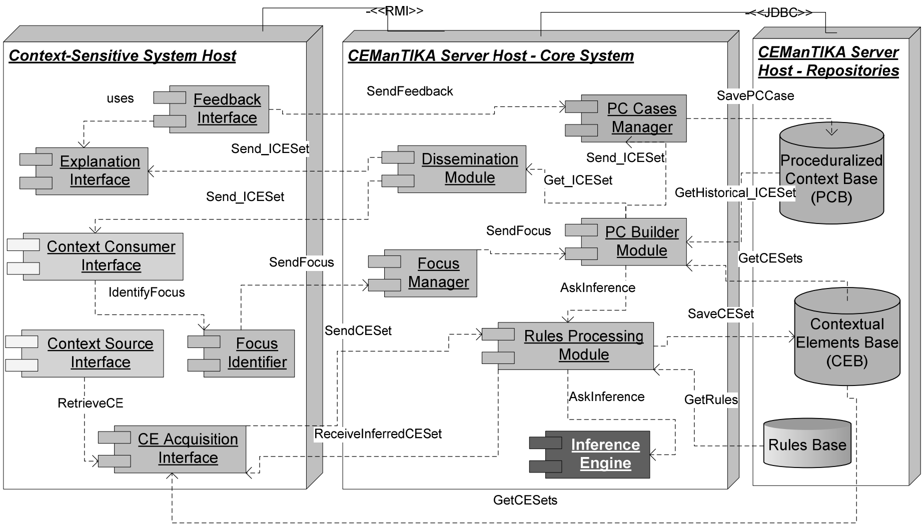

Fig. 3. Overview of CEManTIKA Architecture (using UML notation) [2]

The CEB contents should be compatible with the model COM. The *CEB Construction* occurs by the instantiation of the component *CE Acquisition Interface*, attached to a context source. Each context source is associated to one or more acquisition components. The acquired CE Sets are sent to the *Rule Processing Module* that uses the pre-defined rules and an inference engine to process the CE sets, verifying inconsistencies, and inferring new CE sets that are sent back to the acquisition module.

The *PC building process* is related to the identification of the CEF Set that must be considered to support the current focus and to maintain the PCB. This is done according to the following tasks:

(i) *Focus identification*: the component *Focus Identifier* that discovers what is the user's current focus, sending this information to the *Focus Manager*;
(ii) *Activation of relevant CEs and Rules*: the *Focus Manager* informs the current focus to the *PC Builder* that searches in the CEB for the relevant CEs in the focus and identifies in the Rules Base the rules related to that focus;
(iii) *Building the PC*: the *PC Builder* identifies what are the CE Sets associated with the focus in the CEB and retrieves their instantiated values. Also, the PC Builder looks in the PCB for historical PC built before in a similar focus. With these two inputs and the selected inference rules, the PC Builder identifies which CEs will be considered and builds the final PC;

(iv) *Incremental Acquisition and Learning*: the manager gives the user the opportunity to identify if the chosen CEs were really useful, allowing the user to validate the PC built. To do so the *Dissemination Module* redistributes the built PC set to the *Context Consumer* and to the *Explanation Interface*, which provides the user with an explanation about how the PC was built, including the activated rule and decisions made to restrict the set of CEs considered. The *Feedback Interface* enables that the user indicates how useful was the PC for the task development and how much the PC expressed her/his current context. This feedback is sent to the *PC Cases Manager* that stores the new case in the PCB for later usage.

6 Implementation Issues and Preliminary Results

We are currently working on the development of a prototype of the model COM and the CEManTIKA modules, to verify the viability of its implementation and to validate the modelling proposed. The idea is to develop the model and the manager in a top-down/bottom-up approach, that means develop pieces of the manager and the model in simple domains and to go validating the ideas through small prototypes towards a final more robust solution. This PhD work is part of a bigger project involving teams from the Federal University of Pernambuco in Brazil, and the Informatics Laboratory of the Paris 6 University in France. Not all components of CEManTIKA will be solved in this PhD, being our main focus the modelling and specification of the manager main components and its representation model.

For the prototypes we decided to use the following technological environment: (i) implementation languages: Java for the manager core components and PhP for the users' interfaces; (ii) communication protocols: RMI (*Remote Method Invocation*) for the communication between clients systems and the CEManTIKA Server, and JDBC (*Java Database Connectivity*) as interface with the repositories host; (iii) reasoning technique for the model processing: we are currently working with description logics and first order logic through production rules that are processed by the inference engine JEOPS (*Java Embedded Object Production System*) [25] and the Jena framework [10]; and (iv) storage: the repositories are currently maintained using the MySQL database.

To represent the concepts in the COM model we are using a combination of ontologies and topic maps. We chose ontologies since they enable knowledge sharing between human and software agents, easy knowledge reuse between systems, and can be easily used by inference engines for reasoning. Thus, they are very appropriate to represent the hierarchical structure between the contextual elements and its instances. Topic maps is also an interesting approach because they can be used to organize large sets of information building a structured semantic link network over existing resources [16]. This network allows easy and selective navigation to the requested information. An interesting characteristic of topic maps is that topics can have relationships (associations) with each other and topics can play different roles in different associations.

For us, the approach of topic maps seems ideal since all concepts (in the upper, middle or lower level) can be represented as topics and freely linked with one another through associations. This enables a richer approach and easy the knowledge incremental acquisition providing a flexibility in the contextual elements representation without a rigid hierarchical format. Ontologies enable the formal specification of the concepts, such as entities and contextual elements, and easy the reuse of existing solutions. Thus, we believe that the combination of ontologies and topic maps is a promising approach that could help us to achieve better results in terms of CE definition and navigation through CEs.

As some preliminary results of our work related to *CE Acquisition*, we implemented a prototype of the generic *Context Acquisition Interface* (CAI) (Fig. 3). CAI enables the context acquisition from different context sources and allows a transparency in the treatment of heterogeneous context sources. Each source must implement a sensor with a wrapper to link the source with CAI. We implemented two different types of sensors to acquire information from existing and popular working tools such as Microsoft Office (e.g. Word, Excel, PowerPoint and Outlook) and instant messenger systems (e.g. MSN) [26].

The Office agent was implemented through a technology known as VSTO (*Visual Studio Tools for Office*)[1]. This agent monitors and captures information such as *userName*, *currentDocument*, *currentSection*, *windowIsActive*, *userIsTyping* and *keywords*. The agent also enables some system adaptation, since we included SmartTags (a functionality of Microsoft Word) associated with key words. These SmartTags enable the inclusion of additional functionality such as the activation of a contextual menu with additional features related to the key word. For example if we are reading a text a key word may be the text's author name, and an additional functionality is to insert author's contact information in a contextual menu, so the reader can follow the author to ask for orientation related to the text. The MSN Messenger agent was implemented using a technology named Messenger API[2]. This API enables several event handling in the messenger application such as when a user sign in or sign out (*OnSignin, OnSignout*), when a user changes her/his status (*OnMyStatusChange*), when a new email arrives (*OnUnreadEmailChange*) and others. The contextual elements that this agent monitors and captures includes: *userName*, *status*, *contactsQty*, *onlineContactsQty*, *userIsTyping*, *windowIsActive*.

We also implemented a prototype of a Form Filling Support Agent (FFSA) that enables the creation and filling of dynamic web forms containing CE elements [27]. The user can inform CEs related to its current situation or increment the form with CEs not actually in the system.

In relation to the *CE Processing* we made experiments with context reasoning and processing using the Jena framework and first order logic [28]. These experiments were made over our proposal for context ontology for groupware [14] and applied to a collaborative writing tool. The experiments showed us that it is still difficult to construct a context manager based on ontologies since current technology (languages and reasoning) is immature. The Jena framework is a powerful tool to implement ontology-based reasoning but it lacks documentation and has problems in its current

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[1] http://msdn2.microsoft.com/en-us/office/aa905533.aspx
[2] http://msdn2.microsoft.com/en-us/library/ms630960.aspx

version. However, we believe that it is a matter of time until ontology technologies could be more easily used. One problem we also perceived in using ontology-based reasoning with Jena is the impact of reasoning in the system's performance. The Jena creator admits the problem and suggests the use of external reasoners for faster performance [10]. Also, some authors [29] point out that this problem could be caused by the use of OWL (*Web Ontology Language*), since there are overheads introduced in satisfying the clauses inherent in OWL Full.

7 Final Considerations and Further Work

This paper presented our proposal for a context management system called CEManTIKA, who is centered around two main features: (1) to provide a domain-independent context manager that considers the dynamic nature of context, enabling the flexible and incremental building of a contextual elements base; (2) to promote the use of the current focus to identify and instantiate the relevant contextual elements to support the task at hand (the Proceduralized Context).

CEManTIKA uses a context modelling approach (the model COM) that proposes the separation of the context management concepts from domain and application concepts. We assumed the hypothesis that it is impossible to imagine a context model that is at the same time specific and generic, since context is extremely domain and application-dependent. Thus, we propose that developers of context-sensitive systems rethink the way of modelling their systems including the context management phases in the system building processes and considering the context-related concepts when specifying the system functionalities.

Currently, we are working on the implementation of a prototype of COM based on the integration of two modelling approaches: ontologies and topic maps. To validate the flexibility and reusability of the model we will build instantiations of contextual elements bases related to different domains such as the music's domain (discussed in this paper), academic mission's domain [24] and expertise's domain [30]. We are also working on the further specification of the CEManTIKA components. The verification of the feasibility of the CEManTIKA proposal will be done with its integration with an expertise recommender system named ICARE (*Intelligent Context Awareness for Recommending Experts*) [30]. ICARE aims to indicate users that should be contacted according to a demanded expertise. To provide better recommendations ICARE uses the current context of the recommended expert and also the context of the user that will receive the recommendation.

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Context-sensitive Team Formation: Towards Model-Based Context Reasoning and Update

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Abstract. Selection problems tend to have two aspects: one that is structural and one that is quantitative in nature. Here we investigate a method that allows decisions on both aspects. The paper considers a typical example, that of selecting members for a team, where decisions are based on context information. We show that graph transformations are providing a solution to the structural selection, while logic scoring of preferences allows qualitative decision making. On an implementation level OWL and SPARQL are used to retrieve and update context data.

1 Introduction

Selection problems occur in many aspects of computer systems and every-day life. For example in a service oriented computing system, one finds the need to select a service to complete a task. Or in a collaborative work environment (virtual or not) one finds a need to assemble teams to complete specific projects which in turn requires selecting team members. In the former example traditionally the terms functional and non-functional requirements are used to describe the *structural* selection (a service with the right interface) and a *qualitative* selection (the most suitable service guaranteeing specific QoS requirements).

The latter problem, of team formation, is the one we wish to concentrate on in this paper, as it is easy to explain, has merits of its own and allows us to present the method to solve it – however that method is more generic and the specific problem is to be seen as a case study. To select team members one needs to make decisions based on structural criteria (to find a member who fits the profile required) and a qualitative decision, to find the most suitable (experienced, qualified, …) such member.

Of course these selection problems are influenced by many factors, with one of the most interesting being context: both suggested selection problems are not performed on static domains (services come and go, as do possible team members, e.g. through being unavailable in certain weeks). Context captures the dynamic nature of the problem environment in a way suitable for processing. In general “context is 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”[1]. Context is also a very important source of information in our computing environments.

In this paper we will use the case of team formation to investigate techniques addressing both the structural and the qualitative aspect of selection. The structural selection and update of context will be described by graph transformation rules, visually expressed in a UML-like notation, while the qualitative concern will be handled using the Logic Scoring Preference (LSP).

The paper is organized as follows: in Section 2, a motivating example of team member selection for a Java software project is given. In Section 3, we present our sample context model as a UML class diagram, which can be translated into an OWL ontology. Moreover, the technologies for retrieving of and reasoning about context information are described and we explain how to model the selection problems using graph transformation rules which can be translated into the SPARQL query language for OWL. In Section 4, the modified LSP method for selection and ranking of potential team members is illustrated. Finally, conclusions and future work are discussed in Section 5.

2 Context-sensitive Team Formation

Selecting the right people for establishing a professional team to conduct a specific task is always combined with hard decision problems. These problems often appear in e-business and e-government applications. The problems fall into two categories: structural decision problems and qualitative/quantitative decision problems. The basis for the decision process are provided by a context model capturing amongst others, the people’s characteristics. The structural decision problem is captured by the question: how we can choose people who satisfy the desired context structure? Moreover, the target team formation requirements can also be expressed in this structural way. The structures are a subset of the context model’s properties. The “qualitative/quantitative” is concerned with selecting the best from amongst the people who satisfy the team formation requirements.

Let us consider the following concrete example: A software company needs a professional team of 4 to work on a software project. The people required are an experienced specification analyzer (more than 5 years experience of analysis, having a qualification and currently working in a project team as analyzer), a software architect (at least 3 years Java design experience), and two good Java developers (more than 3 years Java coding experience and interest in web technology). The problem structure is captured by Fig. 1. Please note that we ignore additional people such as testers, managers and integrators in order to keep the problem simple for presentation.

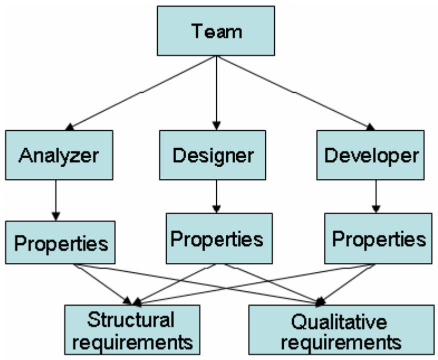


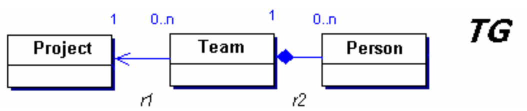
Fig. 1: Motivating example of a software development team

3 Model-based Context Reasoning by Graph Transformation

Since structural requirements can be presented as graphs, a graph-based approach is a natural candidate for addressing the problem. Graph transformations (GT) [2] provide such an approach, combining the modeling of data structures and configurations as graphs with the use of rules to describe the update of these structures. In our case, graphs represent snapshots of context data while rules model context selection, update and reasoning. Apart from this abstract model, which provides the semantic core of our approach, we suggest the use of UML as a human-oriented modeling notation, OWL (Web Ontology Language) as a machine-readable representation of context models, and SPARQL for pattern matching and reasoning on OWL. In this section we will describe these different levels and their relation through examples.

3.1 Graphs and graph transformation

In our approach, graphs occur at two levels. A static context model can be represented as a *type graph TG*, while a system snapshot and states are illustrated as *instance graphs G, H,…*. Dynamic changes regarding the update of structure or attribute values are modeled as graph transformation rules. A graph transformation rule $p: L \rightarrow R$ consists of a name p and a pair of instance graphs L, R over TG. The left-hand side graph L describes the pre-conditions of the rule while the right-hand side R shows the replacement of L after the transformation. The example below shows the type graph, rule, and transformation for transferring personnel between teams in a project.



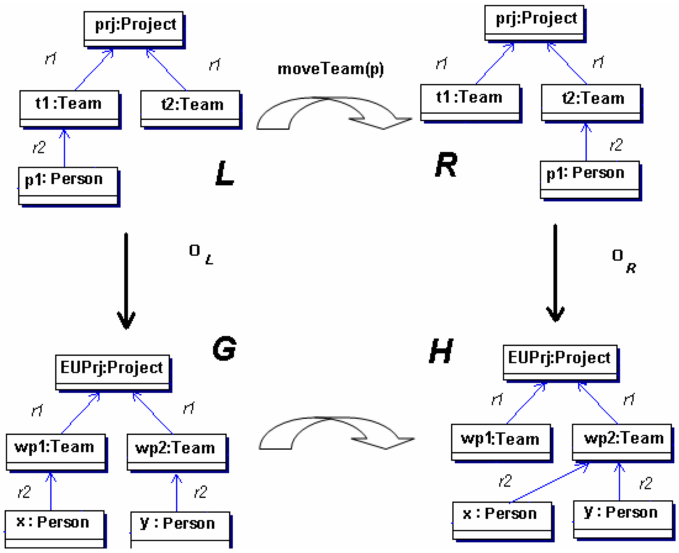


Fig 2: Type graph (previous page) and graph transformation step using rule *moveTeam.*

The rule *moveTeam(p)* specifies how a person *p1* moves from team *t1* to *t2*, both within a common project *prj*. Applying the rule, we are replacing an occurrence of *L* in *G* with a copy *R*, in three steps: (1) Find an occurrence o_L of *L* in *G*. (2) Delete all vertices and edges of G that are matched by *L*. (3) Paste to the result a copy of *R* to generate the new graph *H* [4].

Note that one of the most essential steps in this process is graph pattern matching; we will return our focus to this issue in due course by considering SPARQL queries on RDF/OWL documents to find patterns corresponding to the rule's left-hand side in an instance graph.

3.2 Modeling Technique and Context Representation

As a human-readable front-end, UML provides a visual mechanism for modeling both the static structure of a system and its snapshots at specific times. The UML class diagram is used to describe static concepts such as class, property and class-level relationships, including generalization and association, as well as cardinality constraints. In our approach, graph diagrams are seen as a visual representation of type graphs. Note that we are not using the full power of the language. For example, it is not necessary to define operations or visibility of properties since these cannot be represented in OWL. However, we make use of constraint. Assume that we would want to express two kinds of associations: "*is leader of*" and "*is colleague of*" both represented as self-association of class *Person.* But, as a matter of fact, they are quite different – "*is leader of*" is transitive while "*is colleague of*" is symmetric association. As we need to distinguish one from the other in terms of reasoning, the OCL (Object Constraint Language) can be used to enhance the class diagram as follows.

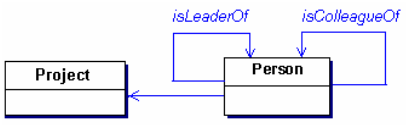


Fig.3: Class diagram (type graph)

```
Context Person inv:
  Person.allInstance->forAll(p1,p2.p2| p1.isLeaderOf=p2 & p2.isLeaderOf=p3
               implies p1.isLeaderOf=p3)
    Person.allInstance->forAll(p1,p2) |
p1.isColleagueOf=p2 implies p2.isColleagueOf=p1)
```

Table 1: OCL constraint for class diagram

This additional information is useful when instantiating the class diagrams. Also at implementation level, as an extension of RDF, OWL introduces the mechanism for describing property and association characteristics, e.g. the <owl:TransitiveProperty> in OWL Lite [5].

An instance of a class diagram is visualized by a UML object diagram, representing a system state and corresponding to an instance graph. Object diagrams are not directly used for modeling, except where fragments of a state are to be investigated, but transformation rules are displayed as pairs of object diagrams as seen in Fig. 3.

Since diagrams are not very suitable for automated processing, we use semantic web languages designed for machine-readable representation of data and documents on the web. Among these, RDF (Resource Description Framework) [7] is a framework recommended by W3C that describes web resources using *subject-predicate-object* triples. For example, *rabbit* (subject) *is a subclass of* (predicate) *mammal* (object). Consequently, RDF triples can be easily represented as vertices V and edges E, so that each edge *e (predicate)* in E connects a source vertex *(subject)* and a target vertex *(object)*. In particular, we can present certain RDF triples as *instance-property-value* in UML object diagram. The OWL (Web Ontology Language) is built on top of RDF but adds more complex properties, characteristics and restrictions. A mapping between class diagrams and OWL can be defined as shown in Table 2 below [6].

UML concept	RDF/OWL concept [1]
class diagram	RDF/OWL Schema
object diagram	RDF/OWL document (instant of schema)
Basic data structure	built-in XML Schema datatypes
Class	<rdfs:Class> <owl:Class>

[1] Some features such as Object property, Transitive property, Symmetric Property, InverseFunctionalProperty , and advanced cardinality restriction are only support in OWL, which is an extension of RDF

property (attribute)	<rdf:Property>
general association	<rdf:Property>
source and target of the association	<rdfs:domain>< rdfs:range>
specified association (transitive association, symmetric association, etc) between classes	<owl:ObjectProperty> <owl:TransitiveProperty> <owl:SymmetricProperty> <owl: InverseFunctionalProperty >
class Inheritance (generalization)	<rdfs:subClassOf>,
N/A [2]	< rdfs:subPropertyOf>
cardinality, OCL restriction (Size-related)	<owl:cardinality> <owl:maxCardinality> <owl:minCardinality >
instance x of class X	<x rdf:ID='X'>
links (instance of association) between objects	instance of <rdf:Property> etc.

Table 2: Concept mapping between UML and RDF

Hence, OWL schemata provide a machine-readable representation to type graphs, while OWL instances correspond to instance graphs.

3.3 Pattern Matching Using SPARQL

As mentioned before, pattern matching is on of the major ingredients of graph transformation. Since OWL instances can be seen as graphs, subgraphs satisfying a certain pattern can be retrieved by executing a query on OWL. There are several OWL query languages available such as SPARQL [8] (SPARQL Protocol and RDF Query Language)[3] and. OWL-QL[4]. Jena is an implementation of SPARQL in Java, which provides a framework for building semantic web applications.

Before we demonstrate pattern matching in SPARQL, we present our sample context model as a class diagram. This does not claim to be complete, but captures the essentials that allow us to present the example and explain the techniques.

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[2] UML does not explicitly support property inheritance.
[3] SPARQL syntax and specification : http://www.w3.org/TR/rdf-sparql-query/
[4] OWL-QL is designed at Stanford Knowledge System Laboratory

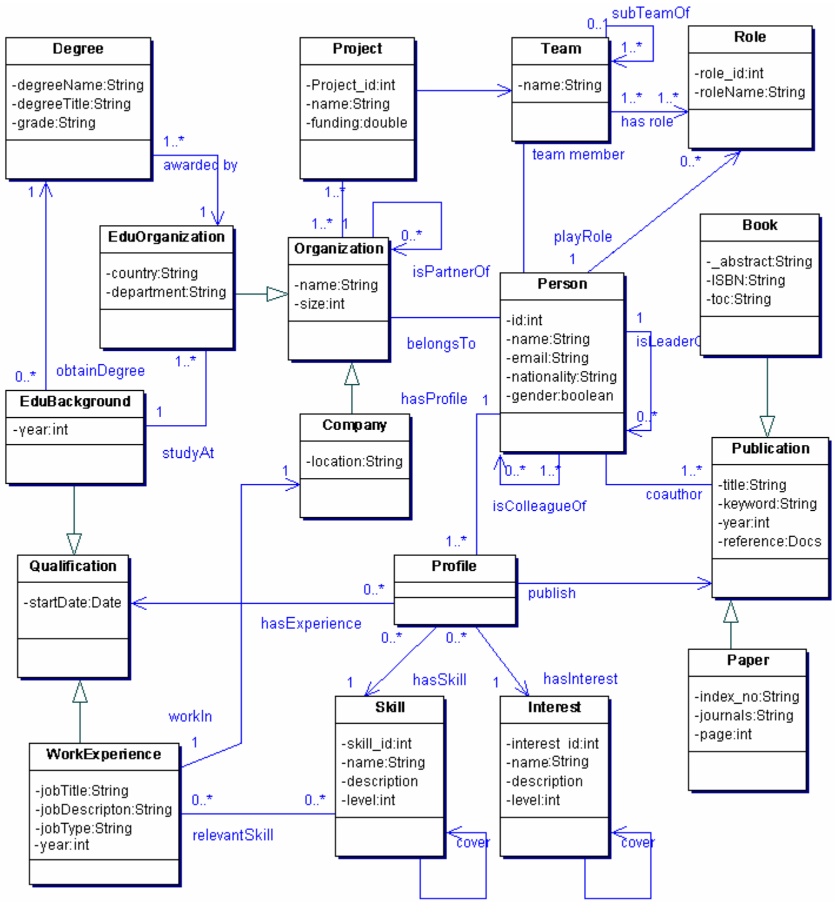

Fig. 4: Context model in class diagram (type graph)

Returning to our example, the software company needs to select a young person to join a new developing group. She should be under 30 and currently working as a programmer with more than 2 years experience in Java coding. We can define a SPARQL query on the OWL document representing an instance of our context model, to match this pattern in the instance graph below.

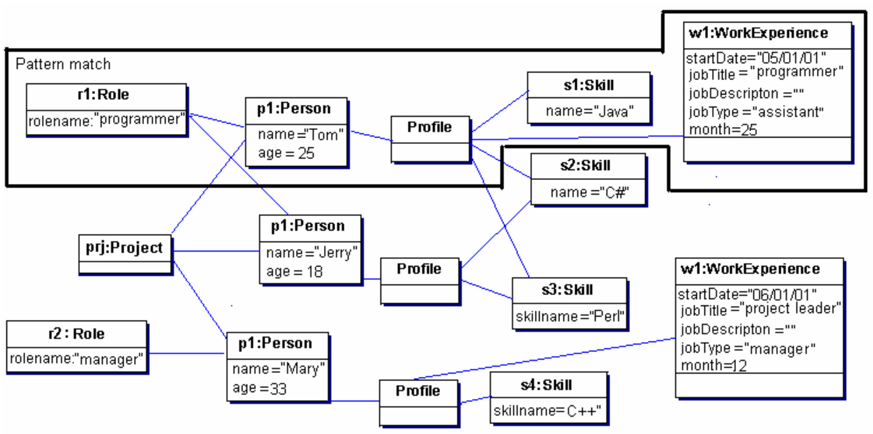

Fig. 5: Pattern matching in partial object diagram (instance graph)

```
PREFIX ns:<http://somewhere.owl#>

SELECT ?p
WHERE {
 ?p ns:playRole ?r.
 ?r ns:rolename "programmer".
 ?p ns:age ?z.
 ?p ns:hasProfile ?profile.
 ?profile ns:hasExperience ?experience.
 ?experience ns:month ?month.
 ?profile ns:hasSkill ?skill.
 ?skill ns:skillname "Java".
 FILTER(?z <=30 && ?month >=24)
 }
```

The SPARQL syntax is similar to other structured query languages such as SQL, the `WHERE` statement indicates a set of triple patterns. The result set will match when the triple pattern all match at the same time. By executing this SPARQL query on OWL instance we are able to detect the relevant subgraphs in an instance diagram that are candidates for context updates or reasoning by means of graph transformation. This is specified more formally in the next section.

3.4 Context Reasoning

It is noticeable that some information may not explicitly be presented in the defined context model. Thus, the problem is that how to derive additional information from given context data. In this paper, we concentrate on the "Rule-based deduction" reasoning method.

The context data is implied by that explicitly present. The rules can be given at metadata or the application level. At the metadata level they are based on the metamodel (the metadata definition) as a type graph. Example includes the transitivity of subclass or subobject (composite) relations, as shown in the following example.

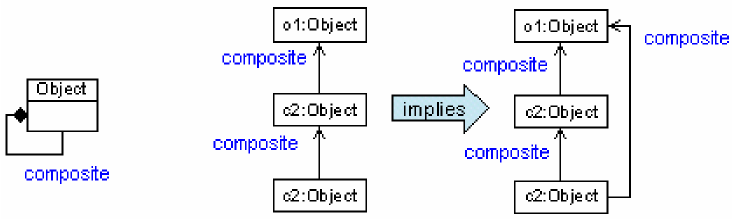

Fig. 6 Deduction-based example – Transitivity

At the domain or application level, where reasoning rules are specific to the problem at hand, they may be probabilistic or based on data obtained through data mining or statistical methods. The following rule (see Fig.7), however, is deterministic, stating that persons who are members of the same team are coworkers. (We use symbol ① *teamMmber*, ② *SubTeamOf*, ③ *isColleagueOf* stands for these associations)

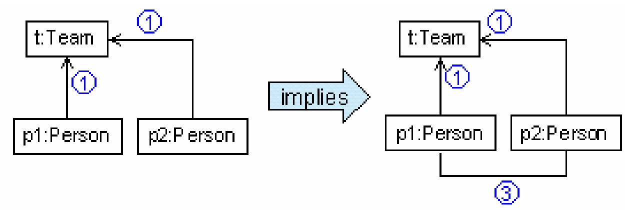

Fig. 7 Deduction-based example - Inference

Applying these two rules in sequence, the following deduction can be made as Fig. 8

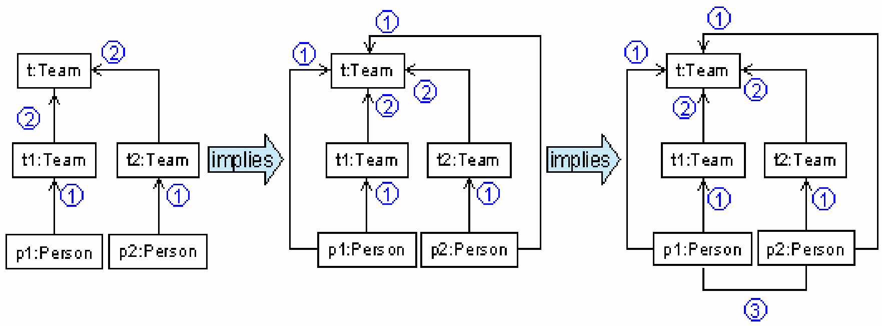

Fig.8 Deduction-based example

How to apply deductive rule in conjunction with SPARQL? One possible approach is to combine Jena inference engine with Jena ARQ. Assume we want to say if “Person a” and “Person b” are working in the same team, then we can apply the example deduction rule to get “a” and “b” are colleagues. This can be defined by Jena rule syntax as follow:

[is_colleague_Imp: (?a belongsTo ?t),(?b belongsTo ?t)->(a? isColleagueOf ?b)]

The inference engine will apply the rules and subsequently add implicit triples to a new generated Inferred graph based on the original model. Then when we execute a SPARQL query to list all isColleagueOf triples, it should be able to return A and B even the links do not exist in the original model. So far, a prototype of reasoning component has been made and accessible via SOAP.

3.5 Team Formation as Graph Transformation

The team formation problem can be separated into two parts, the selection of team members and their actual assignment to the team. The first step corresponds to the graph matching inherent in the application of a transformation rule, while the second is represented by the actual application of the rule. Based on the context model in Fig. 4, seen as a type graph, the team members' context requirements can be given by an instance graph forming the left hand side *L* of the rule in Fig. 6. The graph R presents the intended replacement of this structure by the newly formed team.

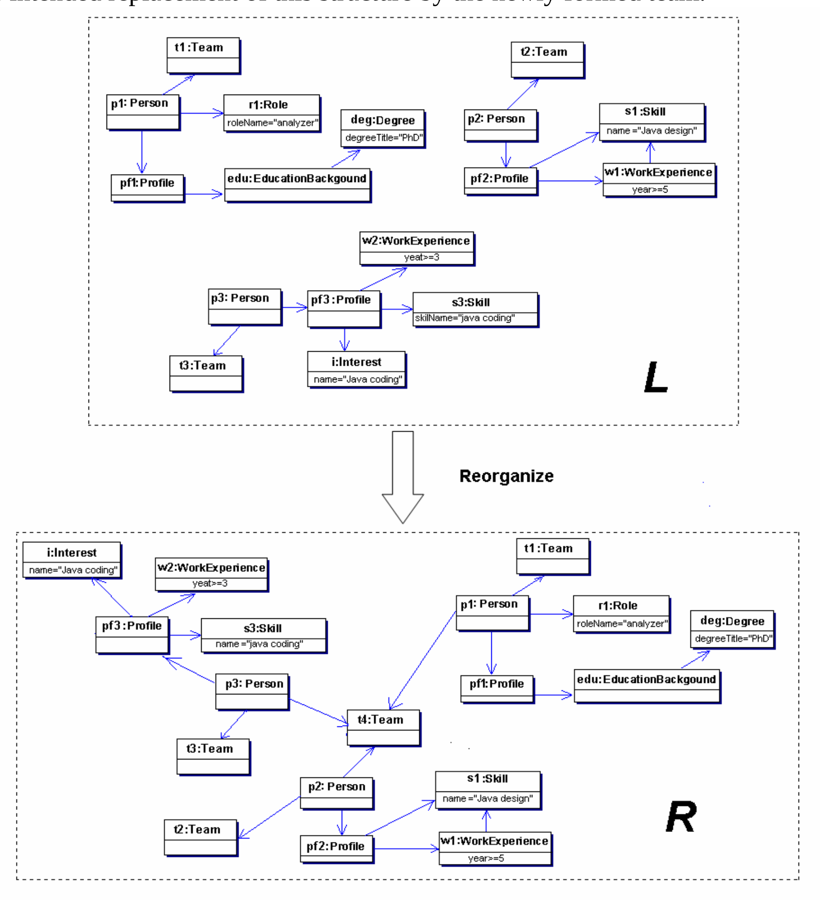

Fig. 6: Specifying the team formation problem by graph transformation rule *Reorganize*

Because the context model is based on an OWL ontology, we can use SPARQL for implementing the three patterns for the candidates' profiles as discussed in section 3.3. The patterns are treated as preferences for the selection. For example, the criteria for searching the correct analyzer are generated by the following query code.

```
  PREFIX ns:<http://somewhere.owl#>

  SELECT ?p
  WHERE {
   ?p ns:playRole ?r.
   ?r ns:rolename "analyzer".
 ?p ns:hasProfile ?profile.
 ?profile ns:hasExperience ?experience.
 ?experience ns:month ?month.
 ?profile ns:hasWorkExperience ?w
 ?w ns:jobTitle ?jt.
 FILTER(regex (?jt,"developer","i") || regex (?jt,"analyzer","i") || regex
(?jt," architecture","i"))
 FILTER(?month >=60)

   }
```

As result, we obtain values for the criteria "rolename", "workExperience.month", and "workExperience.jobTitle". SPARQL returns all candidates satisfying the requirements as given by the structural criteria. In the case of only one candidate for every position we could directly apply the rule and create the only team possible in the present state. However, most of the time we will have a number of suitable potential team members among which we must select the most suitable ones. This corresponds to selecting one of a number of possible occurrences for the application of a graph transformation rule, and this selection will be based on qualitative criteria. The next section realizes this based on a modified LSP method, guiding the graph transformation process by selecting the "best" occurrences for every rule application.

4 LSP Method for Ranking and Selection

LSP is a quantitative method based on scoring techniques and a continuous preference logic [9]. The method allows establishment of an evaluation criterion by specifying the expected properties of a system. To each one of these properties a criterion function is assigned. These functions transform specific domain values to a normalized scale indicating the degree of satisfaction of the corresponding preference. Then, all preference values can be properly grouped using a stepwise aggregation structure to yield a global preference. This can be achieved by means of a preference aggregation function, called *generalized conjunction/disjunction* or *andor*, combining weighted power means to obtain the global preference e_0 as in:

$$e_0 = \left(W_1 e_1^r + \ldots + W_k e_k^r\right)^{1/r}, W_1 + \ldots + W_k = 1 \qquad (1)$$

Where the power r can be suitably selected to obtain desired logical properties (see [9, 10] for further details). However, the disadvantages of the method are that they require the input of a human expert, which is not suitable for working in a dynamic environment [11]. We have defined a modified LSP method which is applicable to finding solutions for dynamic problems. In the rest of this section, we will introduce how to use this method to solve the quantitative aspect of our team formation problem.

4.1 Type-based Unified Evaluation Methods

In order to address dynamic problems such as ranking of structural matches, we have modified the original LSP method. The first change is in defining a unified evaluation method. With regard to the context model defined in section 3, we find that the context information is formatted as four types: Boolean ("gender"), String (such as "name"), Level (such as "skill.level"), and Number (such as "workexperience.year"). Thus, we identified four different evaluation functions to capture these four information types. The four functions are: "*exact match*" (equation 3), "*set overlap*" (equation 4), "*level match*" (equation 5) and "*specific value*" (equation 6).

Typical usage is linked to the data type of the context aspect: if the context aspect can be expressed by a Boolean or a simple string[5], then the exact match would be used; considering sets of information (complex string type), set overlap is useful; level match is useful for ordered discrete values (such as low, medium and high); and finally specific value allows for complex functions that calculate a numerical value (e.g. "workexperience.year"). Because of the link to the data type – which is apparent from the model – it can be automatically determined which function should be used. In addition, the weight $\omega < 0$ expresses that a lower value is desirable, while $\omega \geq 0$ means that a higher value is desired. Thus the global preferences evaluation function is changed from equation (1) to (2).

$$e_0 = (|\omega_1|E_1^r + |\omega_2|E_2^r + \ldots + |\omega_n|E_n^r)^{1/r} \text{ with } 0 \leq E \leq 1, \sum_{i=1}^{n} |\omega_i| = 1 \tag{2}$$

The respective formulas to compute values for these functions (E1 to En) are as follows:

$$E = \begin{cases} 1 & \textit{if criterion is met} \\ 0 & \textit{otherwise} \end{cases} \tag{3}$$

$$E = (e_1 + e_2 + \ldots + e_n)/n \text{ with } e_i \text{ being a score for each element of the set} \tag{4}$$

$$E = {}^{i_c}\!/_{i} \text{ where } i \text{ is the number of levels and } i_c \text{ is the current level match} \tag{5}$$

$$E = \begin{cases} 1 - \left(\dfrac{v_{\max} - v}{v_{\max} - v_{\min}}\right) & \textit{iff } \omega \geq 0 \\ \left(\dfrac{v_{\max} - v}{v_{\max} - v_{\min}}\right) & \textit{otherwise} \end{cases} \tag{6}$$

[5] Simple string means that only one kinds of string is filed in context attribute, for example the "name" of the people in the context model has to be one. Contrast to that the complex string is multi values for one attributes such as "qualifications".

v_{min} being the minimum value for all people, v_{max} the maximum value and v the value for the current people in (6).

4.2 Dynamic Logic Calculation

The second significant change is that we design an automated calculation method (ACM) to find a single logic GCD (Generalized Conjunction/disjunction) function based on Continuous Logic [12] for all preferences. For this to work, all weights of preferences sum up to 1. (The logic meaning can be reflected by a meaningful weight, details on deciding on which is out scope of this paper.) We consider the value of the weight ω_i belonging to a set $A, A \in (0,1)$. Then we have an ordered set W = $(\omega_{1,...}\omega_n)$, and $\omega_1 \geq ... \geq \omega_n$. Based on the meaning of or-ness in the OWA decision making method [13], we can get the following function:

$$\lambda_{orness} = \frac{1}{n-1}\sum_{i=1}^{n-1}(n-i)|\omega_i|, \omega_i \text{ is the } i_{th} \text{ place in set V} \quad (7)$$

Here V is the ordered set obtained from W be reordering according to the following algorithm: First, find weights $\omega_{1+1,...,}\omega_{1+i}$ equal in value to ω_1 and put them to the tail of the set. Second, taking all $\omega_{2+1}...\omega_{2+i}$ which have the same value as ω_2 in the new set in front of the $\omega_{n-i}...\ \omega_n$. Repeat the second step until the last element that has not been reordered before. For example, if W = {0.2, 0.2, 0.15, 0.15, 0.1, 0.1, 0.1}, then, V = {0.2, 0.15, 0.1, 0.15, 0.1, 0.1, 0.2} the value λ presents the degree of the "or-ness" as computed by equation (7). The relation between the value of r and the value of λ is shown in Table 3.

Value of λ	GCD Operator symbols		Operation
$\lambda < 0.3333$	GEO	$r = 0$	Geometric mean
$0.3333 \leq \lambda < 0.3750$	C-	$r = 0.2$	Weak QC
$0.3750 \leq \lambda < 0.4375$	C--	$r = 0.5$	Weak QC (-)
$0.4375 \leq \lambda < 0.5000$	A	$r = 1$	Arithmetic mean
$0.5000 \leq \lambda < 0.5625$	D--	$r = 1.5$	Weak QD (-)
$0.5625 \leq \lambda < 0.6232$	SQU	$r = 2$	Square mean
$0.6232 \leq \lambda < 0.6250$	D-	$r = 2.3$	Weak QD
$0.6250 \leq \lambda$	D-+	$r = 3$	Weak QD (+)

Table 3: Relation between the value of r and the value of λ

4.3 Example for Applying the Modified LSP Method

Assume that there are two analyzers satisfying all criteria, but one of them (analyzer_1) has 8 years of work experience and a qualification of “analyzer”. The other one (analyzer_2) has 5 years experience and two qualifications of “developer” and “analyzer”. Additionally, the weight for experience is 0.7 while that for qualification is 0.3. The or-ness can be calculated as $\frac{1}{2-1}((2-1)\times 0.7+(1-1)\times 0.3)=0.7$. Therefore the logical power of r should be 3 (as per Table 3). Then, the scoring algorithm provides the following results:

analyzer_1= $(0.7\times(1-\frac{8-8}{8-5})^3+0.3\times(\frac{1}{3})^3)^{1/3}=0.2370$ and analyzer_2= $(0.7\times(1-\frac{8-5}{8-5})^3+0.3\times(\frac{2}{3})^3)^{1/3}=0.0296$.

These results show that analyzer_1 is clearly preferable to analyzer_2.

6 Conclusion and Future Work

In this paper, we have proposed a process for solving the problem of selecting people to form teams based on context information. The key technologies used are OWL and SPARQL retrieving context at the implementation level. However, more interestingly methods at the abstract level have been defined, like the use of graph transformation to define reasoning rules, structural matching and updates and its enhancement by the LSP to select suitable occurrences of application according to qualitative criteria.

While we have concentrated on a rather narrow example here, we would like to point out that this highlights many aspects that are common to selection problems and the method is applicable in other domains such as service selection in SoC, an area where context is also very important due to the possibility of late binding of services.

This paper lays a proof-of-concept study for an area that we will investigate further, which is the enhancement of graph transformation techniques with methods to select “best” candidate matches.

More practically, we are going to work on the methodology for specifying the weight for each criteria and separating crucial preferences and desirable preferences by defining more context information. Furthermore, we will also continue to work on the theory of verifying the result by using graph transformation.

7 Acknowledgment

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