Narrative reasoning for cognitive ubiquitous robots

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Abstract— **The symbolic spatio-temporal reasoning is one of the major research challenges aiming to increase the autonomy and cognitive capabilities of ubiquitous robots in ambient intelligent systems. In these environments, there are several situations that are governed by complex processes and where multiple events must be correlated with respect to their spatial and temporal ordering to infer the right situation and to take the right decision. Inferring everyday human activities is a typical example that illustrates the complexity of spatio-temporal modeling and reasoning at a high semantic level. The ambition of this paper is to explore the potential of the narrative representation and reasoning for recognizing and understanding situations. This approach uses hierarchical structures of semantic predicates and functional roles of the Narrative Knowledge Representation Language (NKRL) and allows semantic descriptions of entities, events and relationships between events. A scenario dedicated to the monitoring, in smart home, of elderly people is presented and analyzed to show the feasibility of the proposed approach and its capacity to explain causal chains between observed events.**

I. INTRODUCTION

There is a growing consensus in the robotics community about the need of adding some "deep reasoning" capabilities to the artefacts they actually produce. This will allow these tools to go beyond their (relatively limited) present possibilities of taking given situations into account and to be able to deal in an "intelligent" way with complex activities like planning, monitoring, recognition of complex environments, detection of intentions/behaviours, etc. At the same time, the cognitive science community has developed a whole panoply of tools like advanced knowledge representation systems, powerful inference techniques, semantic-based advanced services etc. that could represent, at least in principle, the best solution for adding more "intelligence" to the robotics-like techniques. The set up of "bridges" between the two communities in order to support the now emerging "cognitive robotics" field would then appear both a logical and useful step. In this respect, there is a recent growing interest in the use of high-level semantic information into robotic systems to face high-level issues related to abstraction and reasoning. Indeed, to enhance intelligence of robots in complex real-world scenarios, recent research trends aim to introduce high-level semantic knowledge in the different functions of the robot such as: mapping and localization [13][14][15][16], scene understanding [17], smart and seamless interactions with human and environment for ambient assisted livings and ubiquitous spaces[2][18][19][20][21].

Most of the proposed approaches in this context concern the use of OWL-based conceptual tools. For example, the authors in [12], propose a software toolbox called Cognitive Robot Abstract Machine (CRAM) for the implementation and control of complex mobile manipulation robotic tasks. Based on Prolog, the core of CRAM allows first-order reasoning while knowledge is represented in OWL-DL. Another framework called Ontology-based Multi-layered Robot Knowledge Framework (OMRKF) is proposed in [6]. Its architecture is quite complex knowing that it includes four classes of knowledge: perception, model, activity and context, and that each level of knowledge includes three knowledge layers (high level, middle level and low level knowledge layer). Each knowledge layer has also 3 ontology layers: meta ontology layer, ontology layer and ontology instance layer. Two types of prolog-based rules are used: rules for uni-directional reasoning in the same knowledge class, and rules for bi-directional reasoning between different knowledge classes. To solve space sharing problems in human-robot interaction, authors in [4], propose SpaceOntology, an OWL-DL ontology. This ontology is constructed to allow a knowledge representation for modeling space (spatial entities, hierarchical organization), spatial relations and fuzzy information. The latter is used to model the imprecision of spatial description using linguistic variables such as close to, far from, etc. In [10], the work aims to endow the robot with semantic capabilities by relying on a richer multi-ontology approach where two different hierarchies are used for spatial knowledge (based on [11]) and for semantic knowledge. The information in the two hierarchies is combined in different ways to provide the robot with more advanced reasoning and planning capabilities. More general, other approaches propose semantic integration middleware dedicated for the sharing of knowledge and services between networked robots. In this context, we can mention first the PEIS-Ecology project that is distinct in its emphasis on the fundamental issue of heterogeneity of robots functionalities in ubiquitous environment [20]. Peis Ecology is middleware for highly heterogeneous distributed systems, self configuration and dynamic re-configuration, cooperative perception, and the integration between digital and physical interaction. One of the interesting functionalities of the PEIS kernel middleware is the semantic matching. This algorithm determines if between the software components listed in the knowledge base there exists some components that matches a category or functionality expressed in the request.

The Ubiquitous Robotic Companion (URC) project aims also at providing a framework for the design and implementation of a semantic-based ubiquitous robotic space (SemanticURS) [24]. The latter enables automated orchestration of networked robots tasks, using HTN SHOP2 planning system. Robot services, sensors, and devices are represented as semantic web services using (OWL-S) ontology [23]. Services OWL-S profiles are registered into the environmental knowledge bases (KBs), so that a robotic agent can automatically discover the required knowledge and compose a feasible service plan for the current environments. The experiment concerns a user sitting on a sofa in a living room carrying his RFID tag, and commands the robot in the kitchen.

The main domain application on which we will focus in this paper is the human-robot interaction in ambient intelligent systems (e.g., smart homes). These systems are intended to monitor and interact with an environment populated by humans and artefacts. The concept of robot companion has been recently proposed by roboticians as a solution to provide assistive services to humans, such as health monitoring, well being, security, etc. Improving the quality of human-robot interaction requires robots to be endowed with spatio-temporal representation and reasoning abilities about dynamic spatial and temporal phenomena. In ambient intelligent systems, there are several situations governed by complex processes and where multiple events must be correlated with respect to their spatial and temporal ordering to infer the right situation and to take the right decision. Inferring everyday human activities is a typical example that illustrates the complexity of spatio-temporal modeling and reasoning at a high semantic level. The literature shows that this type of modeling and reasoning has not been sufficiently investigated in the field of cognitive robots. In [8], the authors have presented a mobile robot using a W3C reasoner like RACER to infer information about an environment of OWL-based conceptual tools. However, as the authors themselves acknowledge, the very limited and static type of ontology used that contains only physical entities like areas, corridors and living rooms makes it difficult for the system to represent and reason about dynamic events and situations like recognizing a person who grabs a door handle in order to open this door. The work by Capezio et al [9] go beyond these limitations, by including in the ontology dynamic entities intended to be used for situation modeling and situation assessment. In their system, one can represent both general notions like ToBeSomewhere and domain specific notions like TurnOnStove, etc. These notions, in a typical Description Logics (DL) style are included in a TBox whilst their instances are stored in the corresponding ABox. Gi Hyun Lim et al propose a situation reasoning technique for robotic applications [22]. This technique is based on an integrated approach that combines low-level sensory patterns and high-level semantic knowledge using Hidden Markov Model (HMM) and Service oriented Context Ontology (SCOn) . The SCOn ontology allows the description of two kinds of contexts: Normal contexts that concern well-going situation according to a service scenario and abnormal contexts that are exceptions to the normal scenario. Normal contexts are related temporally by sequential relationships among them while abnormal contexts have only sequential relationships with normal contexts. Contexts are described in the ontology using two blocks of concepts; a meta-level block for the description of abstract types of concepts and relationships among the concepts including context, object, action, space and human. The service domain specific block allows the definition of specific types of the meta-level context models that corresponds to service domain. The Integrated temporal reasoning using HMMs enables a service robot to understand human-augmented situations immediately whenever the critical situation happens. Ontology instance reasoning is used by the robot to infer both normal and abnormal contexts that will be evaluated in the HMM process to infer the situation from input sensory signal. Experiments on teaching service domain demonstrate that HMM based reasoning on situation allows a service robot to detect successfully normal and abnormal contexts and select appropriate actions.

The ambition of this paper is to explore the potential of the narrative representation and reasoning in the field of cognitive robots. To endow robots with the ability to recognize and understand situations, we aim to propose a semantic formal basis for representing and reasoning about space, change and occurrences within ambient intelligent environments. The narrative-based approach we explore allows semantic descriptions of entities, events and relationships between events. Based on the use of hierarchical structures of semantic predicates and functional roles of the Narrative Knowledge Representation Language (NKRL) [1], this approach consists of the analysis of complex events and behaviors through the use of extended production rules and narrative-(spatiotemporal) reasoning. It can provide a better understanding of the situations under examination, by enabling a robot to dynamically detect changes (context changes) and adjust/adapt its behavior to these changes that can occur anywhere and anytime.

For the validation of the proposed approach, a concrete scenario dedicated to the monitoring, in smart home, of elderly people is proposed. The scenario illustrates the capabilities of the proposed approach in terms of implicit knowledge inference. The paper is structured as follows. Section II presents the foundations of the symbolic representation and reasoning approach. An example of application consisting in situation recognition scenario is presented and analyzed in section III. Finally, a conclusion and future works are given in the last section.

II. Understanding context using narrative reasoning

Ambient environments are characterized by an increasing number of distributed entities (static entities such as table, chair or dynamic entities such as events/actions), complex and structured context/situations. Understanding a situation such as cooking, or predicting an emergency situation as falling, is the main challenge of intelligent systems. However, the difficulty increases when some events are not detected because of sensors or system communication failures for example, leading to ambiguities of interpretation and less reliable understanding. Consequently, providing additional knowledge in absence of explicit information requires: i) a reasoning process based on a chronological and semantic analysis, about past and ongoing events and ii) the use of narrative inference procedures capability to obtain a plausible answer from a knowledge base. To build such environments, a high-expressive knowledge representation model is required to describe complex situations and to take into account both the static and dynamic entities of the environment. Furthermore, suitable reasoning engine should be used to find out a correspondence among the low level features, initially associated with the entities, and the high level model descriptions, included in the world representation of the critical situations recognition and behavior. In fact, the system must be able to i) analyze in real time the stream of information provided by the entity, to understand the situation and consequently to infer the right reaction to be performed and ii) infer all possible causes, consequences (and suggestions for actions) related to these events. Building a correspondence between the low-level features and the high level conceptual descriptions requires an abstract model taking into account static (physical) and dynamic (events and situation) characteristics, roles, properties, etc. of entities. Moreover, ensuring the homogeneity of the Knowledge base (KB) and classifying each entity according to its role, allows to easily aggregate spatio-temporal events into coherent facts shared between the reactive rule and the narrative reasoning.

A. Symbolic Model Representation

One of the main advantages of NKRL is the possibility to build up semantic model of the ambient environment using the following main components that can be associated to each other in order to define very complex scenarios:

1) Ontology of concepts (HClass) denoted by Ω. It corresponds, essentially, to a standard ontology of concepts (C) according to the traditional, binary meaning of these terms. Concepts are inserted into a generalization/specialization hierarchy, often, but not necessarily, reduced to a tree where the data structures represents the nodes of HClass. All concepts (C) are strurctured according to a set of axioms having the form H $\sqsubset$ W where H and W are concepts. An individual (V) is characterized by the fact of being associated, often in an implicit way, to a spatio-temporal dimension. It is represented in upper case like DAVID_, LIVING_ROOM_1 while concepts are represented in lower case. In NKRL, the symbolic labels used to denote both concepts and individuals must include at least an ”underscore symbol”. For instance, individual_person $\sqsubset$ human_ being” denotes that ”individual_ person” is a specialization of ”human_ being”.
2) Ontology of events (HTemp) denoted by Ψ. It is a hierarchy of templates used to represent dynamic knowledge such as moving a physical object. These templates are based on the notion of ”semantic predicate” and are organized according to an n-ary structure that must be understood as the formal representation of generic classes of elementary events.

For example, let us assume that a tag RFID is worn by an elderly person named DAVID, and that the environment is equipped with an RFID Reader. The latter can then detect the presence of DAVID in the living room. The conceptual representation of such an event in NKRL terms is as follows:

aal2.c2) EXIST SUBJ DAVID_: (LIVING_ROOM_1)
date-1: 17/4/2011/21:30
date-2:

Where: EXIST is the semantic predicate” denoting the presence of the human DAVID_ an ”individual”, instance of concept like human being $\in$ C $\sqsubset \Omega$, the location (space) LIVING_ROOM_1$\in$ V $\in$ C $\sqsubset \Omega$, and the temporal symbol date-1 is associated with the timestamp of the information captured in the real world. Using a date-2 symbol allows us to represent events within a certain time interval.
The NKRL representation of the above event corresponds to the general n-ary structure [1] described formally as:

$$(L_i(P_j(R_1a_1)(R_2a_2).........(R_na_n))) \quad (1)$$

where: L_i is a generic symbolic label identifying a given template, P_j is a semantic predicate pertaining to the set (MOVE, PRODUCE, RECEIVE, EXPERIENCE, BEHAVE, OWN, EXIST) and R_k, k $\in$ { 1, …, 7 }, is a generic functional role (see [25] for more details about this topic) pertaining to the set (SUBJ(ect), OBJ(ect), SOURCE, BEN(e)F(iciary), MODAL(ity), TOPIC and CONTEXT). The corresponding arguments encapsulated within a_k, k $\in$ { 1,…, n } are associated to the predicate through one of the functional roles. An argument a_k can consist of a simple concept or individual (an element of HClass) like geographical_location or LIVING_ROOM_1, or of a structured association of several concepts/individuals.
More precisely, the coded event, (aal2.c2) previously supplied, is an instantiation of HTemp template Exist:HumanPresentAutonomously, see Table 1. In this template (in the templates in general), the arguments a_k of the predicate, see Eq.1, are represented by the symbolic variables. The constraints on these variables are expressed in turn as concepts or combinations of concepts using the terms of the HClass ontology. In fact, DAVID is a human_being (see the constraint on var_1, Table 1) and LIVING_ROOM_1 is a location_ (var_2).
Predicates are primitive entities that do not bear a ”meaning” in themselves but that take on this meaning only when they are inserted in a complex conceptual structure like that represented in Eq. 1 above. The notion of role is distinct from that of semantic predicate and is similar, in a sense, to that of ”semantic relationships”, ”conceptual relations”, ”thematic roles” etc. in Computational Linguistics [25].
In the reasoning process, all the explicit variables”, identified by conceptual labels in the var_i style, will be replaced by

$C_i/V_i \subset \Omega$ compatible with the original constraints imposed on the variables.

TABLE I
PARTIAL REPRESENTATION OF AN "EXIST" TYPE OF TEMPLATE

name : Exist:HumanPresentAutonomously
predicate: EXIST
SUBJ var1 : (var2)
!(OBJ)
[SOURCE var3 : [(var4)]]
!(BENF)
[MODAL var5]
[TOPIC var6]
[CONTEXT var7]
var1 = <human_being_or_social_body>
var2 = <location_> | <pseudo_sortal_geographical>
var3 = <human_being_or_social_body>
var4 = <location_> | <pseudo_sortal_geographical>
var5 = <economic/financial_entity> | <financing_process> | <mutual_relationship> | <positive_income> | <purchase_> | <qualifier_> | <reified_event> | <resource_> | <spatio/temporal_property> | <symbolic_label>
var6 = <sortal_concept>
var7 = <situation_> | <symbolic_label>

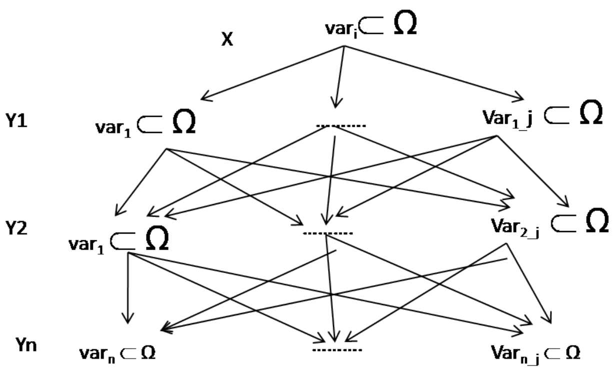

Fig. 1. Inference procedures. The nodes denote the events and the arcs denote the relationship between events. Inference procedures explore all var_i in each Y_i

B. Symbolic Reasoning

In addition to the symbolic representation obtained by making use of the HClass and HTemp ontologies, NKRL provides some deep inference procedures allowing us to obtain plausible answers from a set of factual elementary events by finding implicit relationships among events. All inference rules follow the model represented by Eq. 2 [1] :

$$X \quad iff \quad Y_1 \quad and \quad Y_2 \; ...... \; Y_n. \tag{2}$$

where X is the situation/context to infer and Y_1 , ... , Y_n represent the reasoning steps (encoded under the form of partially instantiated HTemp templates). All rules needed for experiment are stored in the knowledge base of the robot. The inference procedures can be explained by introducing the following example:
Let us suppose that the following events have occurred in the environment: an individual pushes the electrical switch located in the corridor, and the air conditioner stops in the living room. . "ELECTRICAL_SWITCH" is an NKRL concept that is subsumed by the more general concept "technical/electrical_tool", see the example in Table II. The robot tries then to understand the situation (X=why the air conditioner stops working?) in order to propose its assistance (arise an alarm, open windows if necessary, send a message to a technician, etc.) according to the situation inferred (accident, power failure, etc.).
The idle status of the air conditioner is represented in the NKRL context as follows:

aal2.c5)PREDICATE OWN SUBJ(ect) AIR_CONDITIONER: (LIVING_ROOM _1)
OBJ property
TOPIC idle_
date-1: 20/02/2011/08:01:05
date-2:

Let us assume, now, that the robot is able to detect the situation represented by aal2.c5 but that it does not know the specific "cause" of this event that, a priori, can also be produced by the failure of a component of the AIR_CONDITIONER_1. Making use of the inference rule represented in Table 2, it tries now to see whether, among the events registered in the (NKRL) knowledge base of the system, it is able to find some form of stopping/halting event that concerns an electrical device strictly connected with AIR_CONDITIONER_1: it could then be reasonable to suppose that the stop of the conditioner is "caused" by the stop of this connected device. Thus, concretely, the activation of the rule in Table 2 making use of the events registered in Table 3, shows that the detection of a power failure in the air conditioner can be reduced to i) verifying that a stopping procedure has concerned an electrical switch ii) verifying that the electrical switch is really on position "turned off" and iii) verifying that a semantic relationship exists between the two electrical devices (air conditioner and electrical switch): stopping the electrical switch can then be the cause of the idle situation proper to ELECTRICAL_ SWITCH_ 1 device. Of course, other "hypotheses" can be imagined to explain the situation depicted in aal2.c5: each "causal" inference rule that can be envisaged in an NKRL context must always be conceived as a member of a "family" of rules where each of them can supply a "reasonable" explanation of the original event. Operationally speaking, during a (successful) retrieval operation, the variables var_i are replaced by concepts or individuals according to the associated constraints : at the end of the procedure, var_1 is has been replaced by an INDIVIDUAL_PERSON_2 (an instance of human_being), var_2 by ELECTRICAL_SWITCH_1 and var_4 by a the concept coupled_with that is a specific term of the constraint relational_property. var_3 has been bounded to the value AIR_CONDITIONER_1 when the original event aal2.c5 has been taken into account. The robot constructs successfully the path (1,2,4) (Fig 2). To build a robust system, multiple

TABLE II

RULE CONCERNING THE POWER FAILURE OF THE AIR CONDITIONER DEVICE

Y1=PREDICATE PRODUCE SUBJ var1
OBJ activity_stop
TOPIC (SPECIF technical/industrial_procedure var2)
var1 = <human_being >
var2 = <technical/electrical_tool>
——————————-
Y2=PREDICATE OWN SUBJ var2
OBJ property_
TOPIC (SPECIF device_property idle_)
var2 = <technical/electrical_tool>
——————————–
Y3 =PREDICATE OWN SUBJ var2
OBJ property_
TOPIC (SPECIF var4 var3)
var4 = <spatial_relationship, relational_property >
var3 $\neq$ var2
var3 = <technical/electrical_tool >

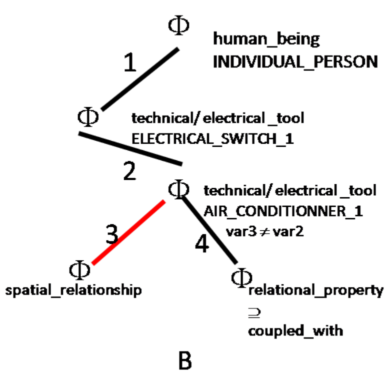

Fig. 2. Reasoning steps (sees the path denoted by (1, 2, 4))

TABLE III

SOME KNOWLEDGE EVENTS STORED IN THE KNOWLEDGE BASE

event=PREDICATE PRODUCE
SUBJ INDIVIDUAL_PERSON : CORRIDOR_1
OBJ activity_stop
TOPIC (SPECIF switch_startup ELECTRICAL_SWITCH_1)
date-1: 17/4/2011/08:00
date-2:
event=PREDICATE OWN
SUBJ ELECTRICAL_SWITCH_1: LIVING_ROOM_1
OBJ property
TOPIC idle_
date-1: 17/4/2011/08:00
date-2:
event =PREDICATE OWN
SUBJ AIR_CONDITIONER_1: LIVING_ROOM_1
OBJ property_
TOPIC(SPECIF coupled_with ELECTRICAL_SWITCH_1)
date-1: 31/10/2010/10:00
date-2:

events must be correlated with respect to their spatial and temporal ordering. NKRL uses the second order structure called binding occurrences like (GOAL, CAUSE).

Remark: A specific template of the OWN type is employed to denote the properties of a (non human) entity, while a specific template of the EXPERIENCE type is used to represent situations where a given entity, human or not, is subject to some kind of experience/happening/event. For example.

aal1) PREDICATE OWN
SUBJ DAVID: (LIVING_ROOM_1)
OBJ property_
TOPIC lying_position
date-1: 17/4/2011/20:10
date-2:
aal2) PREDICATE EXPERIENCE
SUBJ ROBOT_1
OBJ ALARM_SITUATION_1 :LIVING_ROOM_1
TOPIC (FALL_1 hypothetical DAVID_)
date-1: 17/4/2011/20:11
date-2:

III. SCENARIO

A. *General description of the scenario*

The following scenario is dedicated to the monitoring of elderly people in a smart home. It demonstrates the feasibility of the proposed narrative reasoning. In this scenario, it is assumed that there is an elderly person living alone. He/she wants to prepare a meal. The robot tries then to understand the corresponding context by performing the following requests: is she/he eating? is she/he preparing coffee, tea, meal, sandwich? etc. Depending on the context inferred, the robot will remind the person to: take her/his medicine, eat a fruit, because for example, she/he ate two hours ago. Preparing a meal or a sandwich are considered as two different contexts; the first one requires using a cooker, an oven or microwave oven, kitchen utensil like pot, baking dish, etc. The environment is instrumented with RFID tags to identify all the objects deployed in the environment. It is also equipped also with pressure sensors placed under the sofa and chairs, that send a signal, when the elderly people lays on or leaves the above entities. We assume that the robot companion is able to perform a self-localization, obstacle avoidance and navigation using existing techniques. It is equipped with its own camera and microphone, allowing, the robot, to forward, if needed, an image of the elderly person at any place and any time, and use the microphone to communicate with her/him. The proposed approach is under implementation on the Pekee II Mobile robot shown in figure 6. This robot is equipped with a Vision 3D+ system, a Pan-Tilt camera, an RFID Reader and an ambient sound sensor.

B. *Design and modeling*

The robot must be able to infer that the elderly person is preparing a meal according to an incoming stream of sensory data. After analyzing events and historical events (Fig 3), the system behave or act in the Smart house, based on a set of rules, and using a set of hypothesis and transformations rules, see (Figs (4-5)). The robot can then infer for example that the elderly person is preparing a meal. According to the NKRL formalism, a situation should be transformed in a query form as follows:

X1= PREDICATE PRODUCE
SUBJ HUMAN_BEING_1
OBJ planning_meal

Where: planning_meal $\sqsubseteq$ personal_activity $\sqsubseteq$ domestic_activity $\in$ ativity_ $\sqsubseteq$ Ω.

To build up automatically a context for an information retrieved within a NKRL knowledge (Fig 3), a transformation rule with triggering pattern (X1) is supposed to be found. Using this rule, a context should be automatically constructed. A causal explanation of the triggering event is found by retrieving, from the knowledge base, information in the style of: i) someone is in the kitchen (Y1); ii) she/he manipulates an entity (E1) which is used for cooking (Y2); iii) she/he is near the stove (Y2) and iv) the entity (E1) is turned on. A detailed formal representation of this rule is given in (Fig 5). The robot cannot assert that the knowledge base includes any information about the use of some type of devices, but it can certify that the individual person moves the baking dish near the oven. The reply can be supplied thanks to another semantic related event stored in the knowledge base. Consequently, the robot infers that the baking dish is used. The absence of direct answer to Y4 (Fig 4) indicates that the system cannot assert that the oven is running but it can certify that the robot heard the noise of the oven. This information is inferred thanks to the related events using the transformation rule.

Remark: Using a microphone to certify that the oven is working should be avoided. The knowledge can be collected using another kind of sensors such as temperature sensor installed near the oven.

IV. Conclusion and Future works

In this paper, a narrative-based approach is proposed for representing and reasoning about space, changes and occurrences in ambient intelligent environments. This approach has shown to be useful to endow ubiquitous robots with the ability to recognize and understand situations at a high semantic level. The reasoning process is mainly achieved through the linking of factual primitives events by using semantic correlations between events over the time. The ongoing work concerns the actual implementation and validation of the narrative engine on the Pekee II Mobile robot. Future works will consist to use, in certain cases, a kind of dialog between the human and the robot to get additional facts to avoid ambiguities and therefore to optimize the reasoning process of the narrative engine for a better understanding of the situations under examination.

Event	NKRL representation
David is in the living room at 19h05:15	EXIST SUBJ DAVID : LIVING_ROOM date-1: 20/02/2011/19:05:25 date-2: Exist:EntityBePresent
David is in the kitchen at 19h25:25	EXIST SUBJ DAVID : (KITCHEN) date-1: 20/02/2011/19:05:25 date-2: Exist:HumanPresentAutonomously
The Wany Robot moves to the kitchen at 19h26:30	MOVE SUBJ ROBOT:(LIVING_ROOM) OBJ ROBOT:(KITCHEN) date-1: 20/02/2011/19:26:30 date-2: Move:AutonomousPhysicalPersonDisplacement
David is near the OVEN at 19h27:30	OWN SUBJ DAVID: (KITCHEN) OBJ property TOPIC (SPECIF near_ OVEN) Date1:20/02/2011/:19h:27:30
David starts the oven at 19h:34:45	PRODUCE SUBJ INDIVIDUAL_PERSON_1: (KITCHEN) OBJ button_pushing TOPIC OVEN date-1: 20/02/2011/19:034:45 date_2
The baking dish is near the oven at 19h:50:12	OWN SUBJ BAKING_DISH OBJ property TOPIC (SPECIF near_ OVEN) date1:20/02/2011/19:50:12 date2:

Fig. 3. NKRL representation of elementaries events

X1= Antecedent	PRODUCE SUBJ *var1* OBJ planning_meal *var1* = human_being
Y1=Consequent1 Human being (var1) must be in the kitchen (var2)	EXIST SUBJ *var1: (var2)* *var1* = human_being *var2* =kitchen_
Y3=Consequent2 This individual person is near (the stove, ,etc.)	OWN SUBJ *var1* OBJ property_ TOPIC (SPECIF near_ *var3*) *var1* = human_being *var3* = consumer_electronics, technical/industrial_tool, cooking_instrument
Y2=Consequent3 The individual person (var1) uses a device. The role of the device is descriped in the ontologie as instrument for cooking	PRODUCE SUBJ *var1* OBJ (SPECIF *var4 var3*) *var1* = human_being *var3* = consumer_electronics, technical/industrial_tool, cooking_instrument *var4* = device_use
Y4= Consequent4 The cooking instrument is running	OWN SUBJ *var3* OBJ property_ TOPIC *var5* *var3*=consumer_electronics, technical/industrial_tool, cooking_equipment *var5* = running_

Fig. 4. Planning meal "Transormation Rule"

<table>
<tr><td>X1
(antecedent)</td><td>PREDICATE OWN SUBJ var1
OBJ property_
TOPIC running_
var1 = hardware_| diagnostic_tool/system |</td></tr>
<tr><td>Y1
(consequent 1)</td><td>PREDICATE EXPERIENCE SUBJ var2
OBJ evidence_
TOPIC (SPECIF var3 var1)
MODAL (SPECIF instrument_cheking var4)
var2 =entity_
var3 = working_noise |working_condition
var1 = hardware_| technical/industrial_tool|
var4= consumer_electronics</td></tr>
</table>

Fig. 5. Working noise "Transformation Rule"

Fig. 6. The Pekee II Mobile robot from Wany Robotics

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