University of Ibadan
Journal of Science and Logics in ICT Research

Towards A First Order Logic Representation of Complex Situations in Natural Language Understanding

B. O. Akinkunmi
ope34648@yahoo.com

Department of Computer Science,
University of Ibadan, Ibadan, Nigeria

Abstract

In natural language understanding (NLU), situations are identified as well as the causal and temporal relations between them. In Episodic Logic (EL), a knowledge representation scheme for NLU, both atomic situations (characterized by simple assertions like “tom greets mary”) and complex situations (characterized by complex assertions such as “everyone greets mary) are allowed as they naturally arise in narrative texts. The problem of allowing both kinds of situation in EL, is that operators extraneous to first order logic are used which interpretation yield statements that treat complex propositional statements as terms the such as: PC(∀x.Greet(x, mary), s) where the predicate PC represents the relation partially-characterizes. This paper develops a formalism based on the situation calculus that expresses simple and complex situations of the same nature as those in EL without leaving the confines of first-order logic as needed when using EL. The approach taken here is to use a reified form of McCarthy and Hayes’ situation calculus(SC) as the basis for expressing complex situations. The ability of the reified SC-like formalism to correctly interpret situations involving complex as well as simple propositions is demonstrated. The achievement of this paper is a major step towards making FOL an adequate semantic representation language for narrative texts.

Keywords- Component, Natural language understanding, Knowledge representation, Semantic interpretation, Complex Situations, Situation semantics

I INTRODUCTION

Language for semantic representation of natural language texts was recently revisited by Schubert [14]. While Allen [2] had voted with using first order predicate logic (FOL) for semantic interpretation, Hwang and Schubert[7] had invented the Episodic Logic as a means of doing semantic interpretation. One of the key add-ons in EL, is the * and the ** operators used to associate propositions with episodes or situations. These operators can associate complex propositions with situations in a way that makes them extraneous to FOL. A first step in arguing for the adequacy of FOL as a formalism for the semantic interpretation of natural language is to find a way of associating complex propositions with situations within the confines of FOL. One advantage of limiting semantic representation within the confines of FOL is that it becomes possible to take advantage of its standard semantics and proof system.

. This paper therefore presents a reified form of situation calculus that allows us to interpret the complex situations of the sort described within episodic logic (EL) without necessarily going through atomic situations as done by Schubert[12] in his work on FOL** and without leaving the confines of first order logic. A clear understanding of the various interpretations of complex situations becomes particularly important in the light of attempts at refining the inferential mechanism of EL [14, 16]. This paper is especially apt now that there is renewed debate as to the ideal semantic representation language for natural language text [14].

The rest of the paper is organized as follows. Section 2 provides a background of the existing literature. This is followed by an axiomatic delineation between Davidson’s atomic events and McCarthy and Hayes situations. Section 3 focuses on the methodology for developing the formalism. It starts by using lambda expressions to define a taxonomy of complex assertions or propositions, and then shows the development of the formalism using a standard FOL template that recognizes situations as a first class object as becoming of a typical situational calculus(SC) –like language. Section 4 demonstrates the outcome of applying the formalism developed in section 3 to representing sample text involving complex situations.
.

B. O. Akinkunmi (2018). Towards A First Order Logic Representation of Complex Situations in Natural Language Understanding, *University of Ibadan Journal of Science and Logics in ICT Research (UIJSLICTR),* Vol. 2, No. 1, pp. 1 - 7.

II. LITERATURE REVIEW

The interest in representing situations in such a way that they can be quantified over and reasoned with have spanned many decades, starting with philosophical literature [3, 11], and then in AI literature [1, 4, 6, 12] . The substantial body of literature built up in the 1980s and 1990s on the subject of ‘reified logic’, was borne out the need to talk and reason about situations or (as Galton[5] called them, *eventualities*) arising in time. Such situations arise naturally in narrative texts as demonstrated by Schubert[12].

Logical descriptions of an assertion that defines a situation can be simple or atomic in nature such that they can be represented by simple factual propositions expressible as a simple relation between known objects in the domain. An example of this is:

John looks at Mary

On the other hand, the logical descriptions of assertions that define other situations require referring to relations among non-specific individuals in the world such as:

Someone touched Yesh

Everyone looked at Josh

The former class of situations can be represented as simple atomic logical statements requiring no quantification over any variable, such as *Look-at(john, mary)*, while the latter class will require the use of a quantification such as is the case in $\exists x.$ *Touch(x, yeshua)* or $\forall x.$ *Look-at(x, josh)*.

While in the earliest paper written about this subject, Reichenbach [11] approach is to allow assertions of any type to be associated with specific situations as they may arise in narrative texts, denoting that a logical assertion is associated with a situation. Schubert[12] concludes that this implies that the relation between assertions and situations is like the entailment relation in situation semantics i.e.

$$\text{situation} \models \text{assertion}$$

Such an association is rather loose, suggesting that an assertion holds (among possible many others) true in a certain situation. This association is known as “partial characterization” in Schubert’s work on Episodic Logic. However because of the need to reason about causational relationship between situations arising in narrative texts, a tighter association between assertions and situations is specified in Hwang and Schubert’s work on Episodic Logic[7]. This relation is known as “full characterization”. This means a situation is fully defined by an assertion. Davidson [3] motivated by an inquiry into logical forms of sentences, would only allow atomic assertions to be associated with situations in a form that is essentially a full characterization as in Episodic Logic. There are no references to complex assertions in Davidson’s paper whatsoever.

In the AI literature, two similar lines of thought to Reichenbach’s and Davidson’s emerged in the 1980s and 1990s when trying to associate assertions to times for which they are true, in reified temporal logic. While it appears that Allen’s properties ϕ, and events ψ associated with time interval t as in the formulae Holds(ϕ, t) and Occurs(ψ, t) respectively, is allowed to be either atomic or complex, Galton[4] precisely limited ϕ to atomic assertions. According to Shoham[15], Allen’s position requires assigning the status of functions to predicates and higher-order functions to quantifiers in order to stay within the syntactic confines of first order logic.

In Schubert(2000) FOL**[12], a calculus is developed that allows one to treat complex situations as joins of atomic ones of the sort described by Davidson. This resulting logic provides a formal semantics for Episodic Logic[7]. In FOL**, a situation can be part of or concurrent part of or segment of another. When a situation s is concurrent part of another situation s′ and the assertion ϕ fully characterizes situation s (i.e. ϕ**s), then $s' \models \phi$. FOL** stops short of offering a first order language syntax for representing narrative text, Thus leaving us with the debacle of how to deal with the operators * and ** within the context of any kind of predicate logic. They are neither first order nor second-order predicates. Schubert apparently, wishes to treat all assertions as terms in a first order logic. However, the expressions of complex assertions require quantifications implying the need to go beyond the confines of FOL.

A. Axiomatic Delineation of Literature’s Situations

Now we will examine two existing first order logical languages that capture the notion of situations. Although the logical statements used for the two of them are not significantly different, their semantics are different in the sense the one by Davidson[3] treats situations as atomic while the other named *situation calculus* due to McCarthy and Hayes[8,9]. As an example of Davidson’s atomic situations, one can express the fact that: *Bola holds office of HoD* as:

Holds-office(bola, hod, e)

The representation of the same, in McCarthy and Hayes’ situation calculus is similar:

Holds-office(bola, hod, s)

The semantic difference between the two languages is that while the situation calculus allows us to associate other propositions such as *Olu holds office of PG coordinator* with the same situation as the one in which Bola held the office of HOD, Davidson’s language does not. As such in situation calculus it is also possible to also have:

Holds-office(olu, pgcoord, s).

As such e is an atomic situation while s is a complex one. From the point the second statement is introduced, e and s no longer describe the same situation. Thus for Davidson's domain of atomic propositions we can have the following first order logical axiom:

Axiom 2.1
$\forall x, y, e, x_1, y_1, e_1.$
$\text{Holds-office}(x, y, e) \wedge$
$\text{Holds-office}(x_1, y_1, e_1) \supset$
$(x \neq x_1 \vee y \neq y_1 \supset e \neq e_1)$

In a more general sense, if P and Q are not related predicates then:

Axiom 2.2
$\forall x, x_1, e, e_1. P(x, e) \wedge Q(x_1, e_1) \supset e \neq e_1$

These foundational axioms are inherently absent in the situation calculus. The implication of this is that if wish to express the fact that bola held office of HOD and that Olu held office of PG-coordinator in the same situation using a Davidsonian language, the best we can do is to create contexts in which Davidsonian situations hold so that we can write:

$\text{Holds-office}(bola, hod, e) \wedge$
$\text{Holds-office}(olu, pgcoord, e_1) \wedge$
$\text{context}(e) = \text{context}(e_1)$

In that case, a context may include information about organization and dates. For example, (Computer_Science_Dept_UI, 2016-2018).

The good side of the situation calculus representation is that it allows the use of first order logical language for associating a complex situation involving quantifications. For example, a situation s in which "everyone looked at Mary" can be expressed as:

$\forall x. \text{Looked-at}(x, Mary, s)$

This statement here is equivalent to episodic logic's ($\forall$x. Looked-at(x, Mary)) * e. Note that the situation is not fully characterized by "everyone looked at Mary". This is the case because situation calculus leaves out a way of completely describing a situation as discussed earlier. However, there is no way of letting a complex assertion fully characterize a situation in situation calculus, such as in the episodic logic statement: ($\forall$x. Looked-at(x, Mary)) ** e

The purpose that a fully characterized situation plays in natural language discourse is that they facilitate the representation of causation, such as in the short narrative text:

Every one looked at Mary. This made her blush.

If the best we can do is have situations partially characterized by the complex assertion, then we will be compelled to state that everything that is part of that situation made Mary blush. That is not what we wish to express.

In order to unify the notion of situations, a proposition is made here for a reified situation calculus language that associates assertions or fluents with situations using the predicate *holds*. The language will reify fluents so that they can be quantified and talked about. The only difference between our language and the reified situation calculus used in Pinto(1994) is that our language is silent about the actions that effect transition between situations. Our language is adequate in providing first-order logic interpretation for Schubert's Episodic logic.

III METHODOLOGY

The approach taken to solve the problem involves first formalising the various kinds of complex assertions that one may deal with in natural language discourse, and then developing a situation calculus like language that allows us to reify those assertions while factoring the quantifications implied in the complex assertions.

A. Assertion Typing by Lambda Calculus

An assertion or fluent, is a propositional element that describes a situation or eventuality. There is an inherent typing of such assertions which we will describe in this section. Such types are described as lambda expressions. For every type of assertion, there is a generic predicate or relation formed around the main action in the statement. For example, we can have *looking* situations, *greeting* assertions, *sitting* assertions. Our running example will describe a looking event between two agents.

The generic type describing simple looking assertions is described by the lambda expression:

$\lambda x \lambda y.\text{Look-at}(x,y)$ …………………………………T1

Type T1 is also equivalent to type T2 below:

$\lambda y \lambda x.\text{Look-at}(x,y)$…………………………………T2

Generally a lambda expression can be applied to specific constants such as john or mary, or to variables in the presence of quantifiers. Statements of this type are statements that result from the application of this lambda expression to two constants. Subtypes of this statement are statements in which one of x or y has been fixed by a constant. This assertion type is a sub type of the generic type $\lambda x. \lambda y.$ Look-at(x, y) which describes the assertion *anyone looks at anyone*. An example of this subtype is $\lambda x.$Look-at(x, mary) which is the assertion type "anyone looks at mary". Another example is $\lambda y.$Look-at(john, y) which is the assertion type "john looks at anyone". That assertion type is super type of such assertions as Look-at(john, mary) and Look-at(alice, mary) which can be regarded as the products of the following lambda applications:

λx. Look-at(x, mary). john $\cong$ Look-at(john, mary)

λx. Look-at(x, mary). alice $\cong$ Look-at(alice, mary)

The application of a lambda expression to a variable in the presence of a quantifier helps to give a substantive binding to a variable as in first order logic.

One example each of lambda applications to variables in the presence of universal and existential quantifiers are given thus:

$\forall z(\lambda x.$Look-at(x, mary)).z $\cong$ $\forall z$ Look-at(z, mary)
$\exists z(\lambda x.$Look-at(x, mary)).z $\cong$ $\exists z$ Look-at(z, mary)

In a sense, we may see "somebody looks at anyone" or "everyone looks at anyone" as a subtype of $\lambda x \lambda y$. Look-at(x, y) in the sense that the role y has been filled by the existential or universal quantifier, while the role x remains open. These subtypes are expressed as the following lambda expressions:

$\lambda x \exists y$.Look-at(x,y)……………………………..T3
$\lambda x \forall y$.Look-at(x, y)……………………………...T4

Type T3 is derived from the application of the inner lambda sub-expression: λy. Look-at(x, y) in T1 to the variable y in the presence of the existential quantifier $\exists y$ thus:
$\lambda x(\exists y(\lambda y$. Look-at(x, y)).y) $\cong$ $\lambda x \exists y$. Look-at(x, y)

Similarly the type T4 can be derived by the application of the inner lambda sub-expression λy. Look-at(x, y) to the variable y in the presence of the universal quantifier $\forall y$ to the lambda expression T1 thus:

$\lambda x(\forall y(\lambda y$. Look-at(x, y)).y) $\cong$ $\lambda x \forall y$ Look-at(x, y)

Instances of the subtype T3 include $\exists y$. Look-at(mary, y) while an example of the subtype T4 is $\forall y$. Look-at(ola, y) which means ola looks at everybody.

From the application of the lambda expression T3 to variable x in the presence of a universal quantifier $\forall x$, we can derive complex assertion:

Everyone looks at someone
$\forall x.\exists y$ Look-at(x, y)

Similarly by the application of T4 to the variable x in the presence of the universal quantifier $\exists x$, we also derive the complex assertion:

Someone looks at everyone
$\exists x \forall y$ Look-at(x. y)

This lambda description of assertion types becomes useful for us in section 4, when we describe how to explain our representation of EL relationships between assertions and situations.

B. Language for Representing Situations

The language used in this paper is a many sorted reified first order logic with equality. The operators not denoted $\neg$, and denoted $\wedge$, or denoted $\vee$, imply denoted $\supset$ and if and only if, denoted $\equiv$, all have the standard first-order logic interpretations. The same holds for the universal quantifier $\forall$ and the existential quantifier $\exists$. The strongly existential quantifier $\exists!$ Is also allowed in our language and should be interpreted as:

$\exists! x.\ P(x) \cong \exists x.\ P(x) \wedge (\forall y.\ P(y) \supset x = y)$

The sorts include assertions, ***F*** situations ***S*** and domain sort ***D***. Assertions are reified. As such assertions which ordinarily are propositional in nature, have the de-facto status of terms. Such terms are formed from the application of fluent functions.The basic predicate involved is Holds with the signatures:

Holds: $\boldsymbol{F} \times \boldsymbol{S} \rightarrow$ Boolean

This predicate expresses the fact that a simple assertion holds in a certain situation such as Holds(f, s) means *a simple assertion f holds in situation s*. This relation is roughly equivalent to the EL's partial characterization relation between an assertion and a situation. Each simple assertion is reified into functions as shown later. Complex assertions are associated with situations by quantifying over variable involved in an assertion mentioned in a Holds atom. For example the EL representation $(\forall x.G(x))$*s will be represented as:

$\forall x$. Holds(g(x), s)

The second predicate contained in this language is Holds**, which has the same signature as Holds. Holds** is roughly equivalent to the EL's notion of full characterization. The formal definition of Holds** in terms of Holds is presented below.

<u>Definition 3.1</u>
*An assertion f Holds** in a situation s if and only if, f Holds in that situation and no other assertion does*.

$\forall$f, s. Holds**(f, s) $\equiv$ Holds(f, s) $\wedge$
$\forall f'$. (Holds(f′, s) $\wedge$ f′= f)

The functions in the language include all other propositional predicates of the domain of discourse used to form fluents. For example, a predicate look-at may express the proposition that someone looks at another. In that case look-at has the status of a function in the language with the following signature:

look-at: $\boldsymbol{D} \times \boldsymbol{D} \rightarrow \boldsymbol{F}$

Another function of this nature is *blush* used for a person is blushing. It has the signature:

blush: $\boldsymbol{D} \rightarrow \boldsymbol{F}$

It is important to note that the formalism described here treat situations which are inherently complex as first class objects in the language so that they can used as objects and they can be quantified over.

IV RESULTS AND DISCUSSIONS

Now the outcome of using the formalism developed in this paper will be presented in terms of its adequacy for interpreting natural language statements involving complex situations. For this cause we will use examples that cover every possible kind of quantifications that can be used to describe a complex proposition. For each example both the EL representation and that of the new SC-like formalism are presented in that order.

The first example is one in which an atomic assertion without any quantification partially characterizes a situation.

Example 4.1
Mary's blushing partially characterizes the situation s.

This is expressed in EL as:

Blush(mary) *s

In our situation calculus language the representation is:

$\exists$s. Holds(*blush*(mary), s)

This particular example raises no problems because the situations in situation calculus naturally allow partial characterization as discussed in section 3. The next example addresses when an atomic assertion fully characterizes a situation.

Example 4.2
Mary's blushing is fully characterizes the situation s. This is
fully expressed in EL as:

Blush(mary) ** s.

In our situation calculus language, the representation is:

Holds(*blush*(mary), s) $\wedge$ $\forall$f. (Holds(f, s) $\wedge$
f = blush(mary))…….4.1

For this example there is a need in addition to associating the fluent with the situation with the predicate Holds, there is a need to rule out the possibility of associating other assertion with that same situation. That is what the second conjunct in the statement achieves.

The next example shows the interpretation of a case in which a universally quantified complex assertion partially characterizes a situation.

Example 4.3
The situation s is partially characterized by everyone looking at Mary. This is expressed in EL as:

($\forall$x. Look-at(x, mary))*s

In our situation calculus language, the representation is:

$\forall$x.Holds(look-at(x, mary), s)

The representation above is made possible by the fact that a situation in situation calculus, can be associated with several atomic assertions. In this case s is associated with every simple proposition of the type λxLook-at(x, mary). The next example interprets the full characterization of a situation by a universally quantified complex assertion.

Example 4.4
The situation s is fully characterized by everyone looking at Mary. This is expressed in EL as:

($\forall$x. Look-at(x, mary))**s

In our situation calculus language, the representation is:

$\forall$x.Holds(look-at(x, mary), s) $\wedge$
$\forall$f. Holds(f, s) $\supset$ $\exists$x. f = look-at(x, mary)

The main difference between the representations in examples 4.3 and 4.4 is the second conjunct which rules out the possibility of associating any fluent with the situation s other than those of the type λx. Look-at(x, mary). The next example shows the interpretation of a case in which an existentially quantified complex situation partially characterizes a situation.

Example 4.5
The situation s is partially characterized by someone looking at Mary. This is expressed in EL as:

($\exists$x. Look-at(x, mary))*s

In our situation calculus language, the representation is:

$\exists$x. Holds(look-at(x, mary), s)

The expression here is facilitated by the fact that we can quantify over an argument of the function resulting from the reification of assertions of the type look-at. Consider a Davidsonian system in which the appropriate variant of Axiom 3.1 holds, i.e.

$\forall$x, y, e, x_1, y_1, e_1.
Holds(look-at(x, y), e) $\wedge$
Holds(look-at(x_1, y_1), e_1) $\supset$

$(x \neq x_1 \vee y \neq y_1 \equiv e \neq e_1)$

It will be hard within such a context to interpret the statement:

$\exists x.$ Holds(look-at(x, mary), e)

As such the statement is inappropriate in such a system. The next example shows the interpretation of a case in which an existentially quantified complex situation fully characterizes a situation.

Example 4.6
The situation s is fully characterized by someone looking at Mary. This is expressed in EL as:

($\exists$x Look-at(x, mary))**s

In our situation calculus language, the representation is:
($\exists$x Holds(look-at(x, mary), s)) $\wedge$
($\forall$f. Holds(f, s) $\supset$ $\exists$x. f = look-at(x, mary))

The expression's second conjunct rules out associating s with any assertion that is not of the type λx. Look-at(x, mary). Note that the existential quantifier $\exists$ does not rule out the possibility of more than one person looking at Mary, as the strict existential quantifier, $\exists!$, in example 4.8 would have done. What it rules out is associating any other kind of assertion with the situation s.

In narrative texts, an assertion like "Someone greets Mary" is usually interpreted as $\exists$x.Greet(x, mary). However in most cases, a better interpretation of the assertion is really $\exists!$x.Greet(x, mary) which means that *a particular person greets Mary*.

The next example is of the sort in which a complex assertion with a strongly existential quantification (i.e. $\exists!$) partially characterizes a situation .

Example 4.7
The situation s is partially characterized by the assertion: *a particular person looks at Mary*.

($\exists!$x. Look-at(x, mary))*s

In our situation calculus language, the representation is the same as in Example 4.5 as expressed below:

$\exists$x. Holds(look-at(x, mary), s)

The next example below is of the sort in which a complex assertion with a strongly existential quantification (i.e. $\exists!$) fully characterizes a situation.

Example 4.8
The situation is fully characterized by the assertion: *a particular person looks at Mary*.

($\exists!$x. Look-at(x, mary))**s

The representation in our situation calculus language is given as:

$\exists$x. Holds**(look-at(x, mary), s)

It is important to note the contrast between our representation of Example 4.6 and Example 4.8, which are both instances of full characterization. In both cases an assertion of the type λx. look-at(x, mary) holds in the situation s. The difference between the two is that for the existential quantifier case (in Example 4.6), one only needs to rule out any assertion that is not of the same type holding in that situation, while in strongly existential case (in Example 4.8), we rule out any other assertion f, different from look-at(x, mary) where x is the same person that known to have looked at Mary in the situation s.

The next two examples show our first order representation of two small narrative texts involving some sort of anaphoric references that will easily arise in narrative text. The next example is one on a situation that indicts another.

Example 4.9
The representation for the following text:

Mary reports to Sam that John kicked Pluto

is given thus:

$\exists$s. Holds**(kick(john, pluto), s) $\wedge$
$\exists s_1$. Holds(reports-to(mary, sam, s), s_1)

The final example illustrates two situations and a causation relationship between them.

Example 4.10
The representation for the narrative text:

Everyone looked at Timmy. This made her blush
Is the representation:

$\exists$s.$\forall$x.Holds(looked-at(timmy), s) $\wedge$
$\exists s_1$. Holds(blush(mary), s_1) $\wedge$ Cause(s, s_1)

The final section revisits the debate of an appropriate target language for semantic parsing and shows how our representation can be used to help Allen's reified logic take care of complex assertions.

V. SUMMARY AND CONCLUSIONS

This paper has focused on presenting a first-order logic representation that is adequate for representing complex situations that arise frequently in narrative texts. The formalism resolves the difficulty of determining the nature of the * and ** operators from Episodic Logic, within the context of a predicate logic. Using the language of reified situation calculus, it was possible to eliminate the need for either of both operators through the use of the predicates Holds and Holds**.

In a wider sense, the formalism described in this paper can be adapted to reify such complex propositions in Allen's reified logic. To state that a complex proposition of the type $\forall x.P(x)$ holds at time t in a reified logic, one can reify P into a assertion function status p and then write $\forall x.Holds(p(x), t)$ instead of the first order predicate logic misnomer $Holds(\forall xP(x), t)$ that Galton[4] warns against. However, it must be noted that Allen's time interval are more like McCarthy and Hayes's situation than Davidson's event tokens in the sense that many assertions can potentially be associated with any time interval.

Schubert[14] has argued that EL captures the expressiveness of natural language better than first-order logic except for some restricted application domains, and thus it is a better target language for semantic parsing. However this paper moves towards closing that gap by providing a way of accommodating complex situations within first order logics. Nonetheless, there remain a number of issues that will bring first-order logic closer to EL in expressive power. One poignant example of this is EL's power to capture hypothetical episodes that can arise in natural language discourse such as:

For Tunde to smile is rare.

The representation of this requires that we introduce assertion kinds explicitly in any first order logic that must serve as a target language for natural language text, just as done in EL. That however, is outside the scope of the current paper.

Although it can be shown that a version of the situation calculus language described here (with a slightly enriched ontology) has many of the desiderata that Schubert[14] listed for an ideal formalism for semantic representation, it lacks as much "language-like expressivity" as Episodic Logic.

ACKNOWLEDGMENTS

The author is grateful to the anonymous referee for his helpful comments made on the first draft of the paper. The author is also grateful to Professor Lenhart K. Schubert for access to the early papers on Episodic Logic.

REFERENCES

[1] Allen J.F.(1984) Towards a general theory of time, *Artificial Intelligence*, vol 23(2) pp 123-154.

[2] Allen, J.F.(1985) *Natural Language Understanding,* Redwood City: Benjamin Cimmings

[3] Davidson D.(2001) Logical Forms of Action Sentences, In Davidson D., Ed., *Essays On Action and Events*, pp 105-121,Oxford: Clarendon Press, pp105-121. Also In N. Rescher (ed) *The Logic of Decision and Action*, Pittsburg: University of Pittsburgh Press.

[4] Galton A.(1991) Reified Temporal Theories and How to Unreify Them. In Mylopoulos J and Reiter R., Eds, *Proceedings of the 12th International Joint Conference of Artificial Intelligence*, New York:Morgan Kaufmann 1991.

[5] Galton A.(2005) Eventualities. In Fisher, M., Gabbay D.M., and Vila L. Eds, *Handbook of Temporal Reasoning in Artificial Intelligence*, Amsterdam: Elsevier pp 25-58.

[6] Galton A.(2006) Operators vs. Arguments: The Ins and Outs of Reification. *Synthese* 150(3) pp. 415-441.

[7] Hwang C.H. and Schubert L.K.(1993) Episodic Logic: A Comprehensive, Natural representation for Language Understanding. *Minds and Machines* vol. 3 pp 381-419, 1993.

[8] Lin, F.(2008) Situation Calculus. In van Harmelen, F., Lifschitz, V. and Porter B. Eds, *Handbook of Knowledge Representation*, Amsterdam: Elsevier pp 449-469, 2008.

[9] McCarthy J. and Hayes P. J.(1969) Some Philosophical Problems from the Standpoint of Artificial Intelligence. In Meltzer B. and Michie, D. Eds, *Machine Intelligence* **4** Edinburgh: Edinburgh University Press, pp 463-502

[10] Pinto, J.A.(1994) *Temporal Reasoning In the Situation Calculus* PhD thesis, University of Toronto, 1994.

[11] Reichenbach, H. (1947) *Elements of Symbolic Logic*. New York: Macmillan

[12] Schubert L.K.(2000) The Situations We talk About. In Minker J. (ed) *Logic Based Artificial Intelligence* Dordrecht : Kluwer Academic Publishers pp 407-439.

[13] Schubert L.K. (2014) From Treebank Parses to Episodic Logic and Commonsense Inference. In: *Proceedings of the ACL 2014 Workshop on Semantic Parsing*, pp55-60, 2014.

[14] Schubert, L.K.(2015) Semantic Representation. In Bonet, B and Koenig S. Eds, *Proceedings of the 29th AAAI Conference*, New York: AAAI Press, pp. 4132 -4139

[15] Shoham Y.(1987) Temporal Logics in AI: Semantical and Ontological Considerations. *Artificial Intelligence*, vol. 33 pp. 89 -104

[16] Stratos K., Schubert L.K., and Gordon J.(2011) Episodic Logic: Natural Logic + Reasoning, In Filipe, J and Dietz, J.L.G. Eds, *Proceedings of the International Conference on Knowledge Engineering and Ontology Development* (KEOD 11), 2011 Lisbon: SciTex pp. 304-31