A Situation-Calculus Model of Linguistic Context

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Abstract

This paper develops a logical model based on the situation-calculus of the role of indexicality in creating the linguistic context and how the context changes through the actions of the agent. It looks at indexicals of person, place, and time by showing how the egocentric position is linked towards different objective "maps' of space and time. Multi-participant discourse sets up relations between between the turn units of conversation, while narrative discourse demands relations between the context and embedded context.

Keywords

Discourse, Indexicality, Context, Situation Calculus

1. Introduction

This paper proposes an approach to representing the context created by and used for interpretation of indexical signs in language (including deictics, conversational sequences, and more as well) and human behavior (including actions, appearance, etc.). It is based on the integration of approaches to formalizing context as first-class objects [1, 2], the situation calculus [3, 4, 5] for representing actions, text world theory for providing a cognitive model of discourse functioning [6, 7], an anthropological understanding of langauge as part of human activity [8, 9, 10, 11, 12], as well as the literature on pragmatics and conversation analysis [13, 14, 15]. The result is a representation of the context created by the indexical signs in conversation[8] and more generally human activity[16, 9, 17, 18, 19]. This is the context needed to interpret each utterance as well as the whole discourse. The work here expands upon parts of an earlier presentation in [20].

The indexical mode of signification [21] can be summarized in the following way:

> indexical sign-vehicles point from an origin that is established in, by and 'at' their occuring as the here-and-now 'center' or tail, as it were, of a semiotic arrow. At the terminus of the radial path, or arrowpoint, is their indexical object, no matter what the perceptual and conceptual dimensions or properties of things indexed [11].

The index may simply reinforce the previously estalished context, or may alter the context.

The work presented here considers only the target representation of the discourse in the framework developed here. The automatic conversion of a textual representation into that used here is not considered at this time. Additionally, methods for reasoning with the represention (i.e., deriving what holds in new contexts) as actions (in particular acts of speaking occur) is not

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considered. But the reason for utilizing a representation language based on the situation calculus is to make use of the relative large body of literature on automatically deriving conclusions from a set of expressions in the situation calculus.

The representation language based on the situation calculus is described in Section 2. Section 3 discusses the analysis of deictic expressions in natural language. The default egocentric use of these expressions is illustrated in Section 4. An example of narrative discourse is given in Section 5 and an example of conversational discourse is given in Section 6. Finally, in Section 7 the work is briefly summarized and future work is discussed.

2. The Representation

Following McCarthy and Buvač[1], contexts are *terms*. To state that a proposition p is true in context c, we write IST(c, p) meaning that p is true in the context c. Hence, predicates or fluents (predicates that change truth values from situation to situation) are reified (i.e., are terms). We have the capability to represent (and ultimately reason about) the characteristics of contexts/situations. Speaking situations will generally have a speaker, a hearer, a time, a place and other features. For example, SPEAKER$(c) = \text{P}_1$, TIME$(c) =$ "$4:00PM$", HEARER$(c) = \text{P}_2$, PLACE$(c) =$ "$NewJersey$". We can allow multiple values by using predicate notation such as HEARERS(c, P_3), HEARERS(c, P_4). This is often more convenient than using IST, but something like TIME$(c) =$ "$4:00PM$" is equivalent to IST$(c,$ TIME $=$ "$4:00PM$").

The situation calculus (following the presentation in [22]) is a first-order language for representing dynamically changing worlds in which all of the changes are the result of named *actions* performed by some agent. Here, we merge contexts and states. There is no difference. If α is an action and s a situation or context, the result of performing α in s is represented by DO(α, s). The constant C_0 is used to denote the initial situation or context. Relations whose truth values vary from situation to situation are called *fluents*. Here, following the work on context, they are reified and represented as terms. Although the use of reified fluents in the situation calculus is less common (than the alternative approach of using predicate symbols with a situation argument), it has been used and has been shown to be more expressive [23]. So here the practice in the literature on contexts is followed. For example, IST$(c,$ BROKEN $(\text{OBJ}_1))$ means that object OBJ_1 is broken in situation c. Use of the situation calculus allows one to represent the effect of the different actions on the relevant fluents[3, 4, 5].

It is necessary to provide for all actions, action pre-condtion axioms, positive-effect axioms, and negative-effect axioms. These axioms are compiled into successor-state axioms that specify completely the truth of fluents in a situation/context in terms of the the truth of those fluents in the preceding situation and the action that was performed to get to the current situation/context. Where convenient, an abbreviation for a sequence of actions is used. For example, instead of DO$(act_3,$ DO$(act_2,$ DO$(act_1, c)))$, an alternative is DO$([act_1, act_2, act_3], c)$.

The special predicate CONTEXTCREATION(t, c_1, c_2) captures the world creation notion of text world theory[6, 7]. So, context c_2 is created within context c_1. The t represents the type of creation. This can be "narrative" or "cognitive" or "epistemic", or "intentional, or "hypothetical". Worlds in the sense of text world theory are represented by contexts. Another type of context is called a frame [24] to indicate that it is less fully specified than a context and provides directions

for reference. Examples are "spatial" and "temporal" frames.

The special predicate REFERS(s, o) is used to indicate that the stretch of speech s refers to object o. This is an initial approximation of reference having occurred and a more fine grained analysis is planned for the future given the complexity of the notion [25, 9, 11, 12]. The predicate ARROW$(s, target, type)$ is used to indicate that s (could be a linguistic element) indexically points to the *target* with an indexical relationship of the type *type*. The role of *target* and *type* will become clear with later examples.

Speaking can be represented as with any other action. Certainly in general acts of speaking occur with other actions. We represent acts of speaking as DO$(speak(p_i, utt_i, props, s))$. Here the p_i is the speaker of the utterance, utt_i is the transcription of the utterance, and *props* constitute salient properties of the utterance. These ideally would be automatically extracted from the text of this utterance and others, but for the time being are manually placed in the list *props*.

3. Deictic Expressions

Deictics are in the terminology of Jakobson[8], analyzed as *shifters*. These are elements of the linguistic code (C), the general meaning of which cannot be defined without reference to the message (M), hence, C/M. The message is being spoken by a particular person, at a particular time, at a particular place and in the context of previous and following speech and actions. All of this is located in the context (world/situation) of the representation developed here.

Jakobson distinguishes between the narrated event (symbolized as E^n), the speech event E^s, a participant of the narrated event P^n, and a participant of the speech event P^s. In the representation developed here, E^s is the context created by the action of speaking, while E^n is the context (text world) created by the speech. It is in this context that the actions being talked about actually occur. The participants of the speech event P^s are people who exist in the context in which speaking takes place, while the participants of the narrated event E^n are people who exist in the narrated context, created as a new context within the context in which speech takes place.

Person deixis P^n/P^s relates the participants of the narrated event to those of the speech event. The use of the first-person (*I* in English) signals that the participant in the narrated event is identical to the speaker of the speech event. Therefore the first argument to the action SPEAK is identical to the person denoted by *I* in the context related by the world creation predicate. The second-person (*you* in English) signals the identity of a participant in the speech event with the hearer in the speaking context.

Tense, symbolized as E^n/E^s relates the time of occurrence of the narrated event to that of the speech event. The present tense may indicate that the speaking occurs at the same time, while the future tense may indicate that the narrated event occurs later than the speech event. The use of tense (along with aspect) in English and in the languages of the world is complex [26, 27, 7]. Handling the complexity is beyond the scope of this paper, but part of the larger project.

Mood, symbolized as $P^n E^n/P^n$ "characterizes the relation between the narrated event and its participants with reference to the participants of the speech event[8]." It reflects the speaker's

view of the action in the narrated event. This is captured in the representation developed here by the different first arguments to the predicate $\textsc{ContextCreation}(t, c_1, c_2)$.

There is also *place deixis* [26, 27, 28] that situates an entity in the event of narration spatially with respect to the event of speaking. Examples from English are *here*, or *there*. Background knowledge is needed to calibrate the nature of the space. For example, *there* can refer to the table in view or to some place thousands of miles away. Through the interpretation of deictic expressions, the context is constructed. Examples are found in the following sections.

Deictics combine both a referential and an indexical function [9, 11, 12]. There is always an index[21] to the center (Bühler's *origo* [29]) of the speech event. Then the reference may be to a place or object proximal to the center (e.g., *here* or *this*) or distal to the center (e.g., *there* or *that*). The reference depends on the index. This is illustrated in the next section.

4. Egocentric View

If the utterance below is said by a detective investigating a crime scene, the interpretation of *here* is in the very place where the speaker is, or alternatively if the speaker is pointing or glancing towards a place nearby.

$$\textsc{do}(\textsc{speak}(a, utt_1, [S, here_{15}]), s))$$
$$utt_1 = He\ was\ stabbed\ right\ here$$

In *props* S represents the characterization of the utterance as a statement and $here_{15}$ is a segmented piece of the utterance (the 5th word). We have:

$$\text{IST}(c, \textsc{Arrow}(here_{15}, loc, e))\ \ \text{IST}(c, \textsc{Refers}(here_{15}, o))\ \ \text{IST}(c, \textsc{Proximal}(loc, o))$$

where $c = \textsc{do}(\textsc{speak}(a, utt_1, [S, here_{15}])s))$ The e in $\textsc{Arrow}(here_{15}, loc, e)$ stands for egocentric, a default pointing to the current location of the speaker.

In response to a question about where someone's coffee cup is located, in the following *there* refers to a place some distance from the speaker, perhaps being "pointed to " either literally through a pointing action or through a glance.

$$\textsc{do}(\textsc{speak}(a, utt_2, [A, there_{25}], s))$$
$$utt_2 = It\ is\ right\ over\ there$$

In *props* A represents the characterization of the utterance as an answer to a question and $here_{25}$ is a segmented piece of the utterance (the 5th word). Now, we have:

$$\text{IST}(c, \textsc{Arrow}(there_{25}, loc, ego))\ \ \text{IST}(c, \textsc{Refers}(there_{25}, o))\ \ \text{IST}(c, \textsc{Distal}(loc, o))$$

where $c = \textsc{do}(\textsc{speak}(a, utt_2, [S, there_{25}], s))$

5. Narrative Example

Here is the first part of an example based on one used by Werth[7].

> I read in today's Guardian, over there on the table, an interesting story. A Naples man who kept cocaine in his mother's tomb was arrested yesterday by drug agents posing as cemetery workers, police said.

Let S_1 represent the first sentence from the above account, S_2 the second sentence, and S_3 the third sentence.

The term C_0 is used to denote the initial context. This is the context of what Werth [6, 7] calls the *discourse world*. The speaker says the above paragraph. Assume that the speaker is P_1, then in the discourse world the result of the speaking of the first sentence is the context $\text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_1, \mathit{props}), \text{C}_0)$, the context resulting from the second sentence is $\text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_2, \mathit{props}), \text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_1, \mathit{props}), \text{C}_0))$, and so on.

A number of things are asserted within context C_0. [Not all are given here.]

$$\text{IST}(\text{C}_0, \text{EXISTS}(\text{OBJ}_1) \wedge \text{NEWSPAPER}(\text{OBJ}_1))$$
$$\text{IST}(\text{C}_0, \text{EXISTS}(\text{OBJ}_2) \wedge \text{TABLE}(\text{OBJ}_2))$$

There is an initial reference to the newspaper and the table. So, we have

$$\begin{aligned}&\text{IST}(\text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_1, [S, \mathit{there}_{17}, \mathit{table}_{1,10}, \mathit{Guardian}_{1,4}]), \text{C}_0),\\ &\quad \text{ARROW}(\mathit{there}_{17}, \mathit{loc}, e) \wedge \text{DISTAL}(\mathit{loc}, o) \wedge \text{REFERS}(\mathit{there}_{17}, o) \wedge\\ &\qquad \text{REFERS}(\mathit{table}_{1,0}, \text{OBJ}_2) \wedge \text{LOCATION}(\text{OBJ}_2, o) \wedge\\ &\qquad\quad \text{REFERS}(\mathit{Guardian}_{1,4}, \text{OBJ}_1) \wedge \text{LOCATION}(\text{OBJ}_1, o) \wedge \text{ON}(\text{OBJ}_1, \text{OBJ}_2)).\end{aligned}$$

The speaking of the sentence has created what Werth [6, 7] calls a *text world* where the reading action takes place. This is a new context. So, we have

$$\text{CONTEXTCREATION}(\text{“}\mathit{narrative}\text{”}, \text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_1, \mathit{props}), \text{C}_0), \text{C}_1)$$

indicating that there is a new context created in $\text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_1), \text{C}_0)$ through the process of narration and that context is denoted by C_1. Additionally, because past tense was used, we indicate that $\text{TIME}(\text{C}_1) < \text{TIME}(\text{DO}(\text{SPEAK}(\text{P}_1, \text{S}_1), \text{C}_0)$. Since, the act of reading occurred within this text world, there is a new context $\text{DO}(\text{READ}(\text{P}_1, \text{OBJ}_1), \text{C}_1)$.

Within the text world describing the act of saying another text world is established. This is the text world where the police announced the crime and the arrest. We have

$$\text{CONTEXTCREATION}(\text{“}\mathit{narrative}\text{”}, \text{DO}(\text{READ}(\text{P}_1, \text{OBJ}_1), \text{C}_1), \text{C}_2)$$

indicating that there is a new context created in $\text{DO}(\text{READ}(\text{P}_1, \text{OBJ}_1), \text{C}_1)$ and that context is denoted by C_2. Additionally, because past tense was used, the relation $\text{TIME}(\text{C}_2) < \text{TIME}(\text{C}_1)$ is added. It is necessary to specify in C_2:

$$\text{IST}(\text{C}_2, \text{EXISTS}(\text{P}_5) \wedge \text{POLICE}(\text{P}_5))$$

6. Conversational Example

Consider the example [30, 31] of a recorded, transcribed, and analyzed conversation between two students at the University of Chicago. It was recorded in a laboratory [32] but seems to be very natural. As is usually the case, there is considerable overlap in the speaking turns of the two participants called Student A and Student B. The situation calculus can represent overlapping actions, but for simplicity this is not represented here.

In the literature on conversation analysis [13, 26] contains a rich set of distinctions as to the type of utterance (first-pair part) that is expected to precede the next utterance (second-pair part). Here, we consider the limited set of questions being followed by answers. An extended set of pairs in this framework is considered in [33].

Prior to the conversation given here there was a mention of speaker B having been in Iowa before. Hence, we have the indexical invocation of a frame[34, 24] in particular a map of the US and the location of cities and universities. Hence the interpretation of place deictics is with regard to this map as opposed to the default egocentric view. This map is part of the commonsense knowledge of all people connected with universities in some way. With regard to the situation calculus implementation, it is assumed that the map has been specified using sentences of logic. Since the map does not change, the symbols specifying the map are not fluents.

DO([

$speak(a, utt_1, [Q])$	$utt_1 = Hu^{?}\acute{u}h\ An'\ how\ do\ you_i\ like\ Chicago\ compared\ [\underline{to}\ \emptyset\,]$
$speak(b, utt_2, [there_{21}])$	$utt_2 = there$
$speak(a, utt_3, [Q, there_{36]})$	$utt_3 = did\ you_i\ go\ to\ school\ there\ \ or\ uh,\ [wa]$
$speak(b, utt_4, [A, there_{46}])$	$utt_4 = [I]\ did\ go\ to\ school\ there$
$speak(b, utt_5, [A, here_{55}])$	$utt_5 = I\ went\ to\ school\ h\acute{e}re\ \acute{a}lso\ [\acute{u}m]$
$speak(a, utt_6, props)$	$utt_6 = [\acute{o}h], h\acute{u}h$
$speak(b, utt_7, props)$	$utt_7 = um\ so\ I_i\ came\ back\ kind\ of$
$speak(b, utt_8, props)$	$utt_8 = I_i\ was$
$speak(a, utt_9, props)$	$utt_9 = [\acute{o}h], h\acute{u}h$
$speak(a, utt_{10}, [Q, here_{10,6}])$	$utt_{10} = An'\ you_i\ w\acute{e}nt\ to\ undergraduate\ \emptyset, h\acute{e}re\ \acute{o}r$
$speak(b, utt_{11}, [A])$	$utt_{11} = \emptyset\ in\ Chicago\ \acute{a}t,\ huh\ Loyola$
$speak(a, utt_{12}, [Com])$	$utt_{12} = \acute{o}h\ \acute{o}h\ I'm\ an\ old\ Jesuit\ boy\ myself_j, [unfortunately]$
$speak(b, utt_{13}, [Q])$	$utt_{13} = Oh\ are\ ya_j\ Where'd\ you\ go$
$speak(a, utt_{14}, [A])$	$utt_{14} = Georgetown,\ down\ in\ Washington$

], s)

Many details of the specification of this example can not be included. Note that in terms of conversational actions, the first question posed by Student A takes place over three utterances and one of those is a contribution of Speaker B. Hence, something like ARROW$(utt_1 + utt_2 + utt_3, \text{SIT}, Q)$ is needed to represent that these three utterances together indexically point to the current situation, setting up the expectation that this question will be followed by an answer. The axiomatization needs to ensure that the ARROW relation persists until there is a matching indexical pointing of an answer. This comes with ARROW$(utt_4 + utt_5 + utt_7, \text{SIT}, A)$. Since

these two match, the two ARROW relations do not need to persist into future situations. The expectation of an answer has been met.

Again with utterance 10 and 11 we have the same relationship in that $\textsc{Arrow}(utt_{10}, \textsc{sit}, Q)$ sets up the expectation that this question will be followed by an answer. Utterance 11 gives the answer and establishes the relation $\textsc{Arrow}(utt_{11}, \textsc{sit}, A)$. At this point the expecctation is met and the axiomatization needs to ensure that the two ARROW relations are matched and therefore do not persist. And then again (B begins to ask questions) we have $\textsc{Arrow}(utt_{13}, \textsc{sit}, Q)$ setting up an expectation that is matched by $\textsc{Arrow}(utt_{14}, \textsc{sit}, Q)$

The relationship between conversational actions form a framework within which the deictics of space (and also time) are interpreted. Note that here the referents of the deictics *here* and *there* are not the immediate location but rather the location expressed on a map of the US with cities and universities (due to the initial invocation of the frame) in these locations[1]. The subscript m is used for the map.

We see that (in athe appropriate situation)

$$\textsc{Arrow}(there_{21}, loc, m) \wedge \textsc{Refers}(there_{21}, Iowa_m) \wedge \textsc{Distal}(loc, iowa_m)$$

all hold. Note that the indexical pointing to the speaker's current location is mediated by the map m and therefore the deictic refers to an element of the map. The meaning of $there_{46}$ is handled similarly. But note that in the situation resulting from utt_5 we have

$$\textsc{Arrow}(here_{55}, loc, m) \wedge \textsc{Refers}(here_{55}, Chicago_m) \wedge \textsc{Proximal}(loc, chicago_m)$$

Later in utterance 10 there is some ambiguity as to whether $here_{10,6}$ denotes the map of universities or cities. This ambiguity is cleared up in utterance 11, but continues into utterance 14 and utterance 15. This sort of ambiguity among related frames is subtle and is not yet incorporated into this framework.

7. Conclusion

This paper has proposed a preliminary combination of the situation calculus (used for representing and reasoning about actions in AI) and notions of linguistic context and indexicality from the linguistic, philosophical, sociological, and anthropological literature. Several different modes of indexicality have been covered: the egocentric indexicality needed in ordinary deictic reference, reference into embedded worlds, the conversational action that sets up an expectation that it will be followed by an action of the appropriate pair-part and the indexicality needed so that deictic reference is transposed onto a frame (e.g., a map of cities and universities).

For the future, the adaptation of reasoning methods from the situation calculus to this context as well is important. Additionally, (although difficult) the hope is to develop methods to automatically translate written texts into the situation calculus representation.

[1]This phenomena of the wide range of possibilities for naming locations has been noted by Schegloff [35].

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