The Attitudes in Discourse Representation Theory and Situation Semantics*

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1 Introduction

Kamp 1990 is an important paper which emphasizes the role of information structure in an adequate treatment of the attitudes and presents this in terms of DRT. Kamp's paper presents the following major insights about the nature of the attitudes:

1. we need a theory of agents' mental states and their relationship to the world in order to be able to give an adequate treatment of the attitude reports. Kamp's paper concentrates on developing this more abstract theory.
2. we need to treat attitudinal objects in a bipartite fashion, representing both the internal state of the agent and the way that this is connected to the objects in the world external to the agent. In DRT this is represented in terms of externally anchored DRSs.
3. within the representation of the agent's internal state there needs to be a representation of background information which the agent might use to identify the objects of which the attitude holds. These are represented in Kamp's DRT by formal anchors within the DRS.
4. there need to be links between discourse referents used in the characterization of an agent's internal state and discourse referents in DRS used to make a (non-attitudinal) claim about the world. More importantly there need to be links between discourse referents used in the characterization of the internal states of agents in order to account for cases of intensional identity. That is, there can be links between two agents' mental states which nevertheless do not require that there actually be an object to which they are referring.

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In this paper I will make the following claims concerning these points:

1. the aim of giving a general account of attitudinal states and not limiting ourselves to semantics for the attitudes is similar in spirit to the situation theoretic approach.
2. the bipartite proposal is essentially similar to proposals for treating the attitudes proposed by Barwise and Perry 1983; Barwise and Perry 1985. In fact it is quite surprising and encouraging that a straightforward recreation of Kamp's analysis in terms of situation theory yields a reasonably precise theory which is a recognizable variant of these proposals.
3. Kamp's notion of formal anchor seems best represented by the notion of restriction provided by situation theory. It is interesting that we can capture the notion of formal anchor within our framework using a theoretical tool that is independently needed.
4. the notion of linking can also be obtained rather straightforwardly by using the machinery of abstraction as developed in Barwise and Cooper 1991; Barwise and Cooper 1993 and Cooper 1992 based on work by Aczel and Lunnon 1991. The λ-calculus gives us a way of making roles in the characterization of mental states fall together by applying them both to assignments which provide new parameters which can be abstracted over. While this approach to sharing is not without its problems, it is not only pleasing in that we do not need to introduce new machinery specific to the attitudes, but also in that it gives us a particular view of what is meant by sharing discourse referents. It appears to give us one route towards a formal theory of mental states distributed over more that one agent.

In addition I claim that the machinery we develop, coupled with the standard assumptions about the non-well founded nature of situation theory automatically gives us a treatment of mutual belief along the lines presented in Barwise 1989.

2 DRSs as predicates

The central claim behind the reconstruction of DRT in situation theory is that DRSs are to be regarded as predicates, that is, either relations or types in the sense of Barwise and Cooper 1991; Barwise and Cooper 1993. Important here is Barwise and Cooper's use of Aczel-Lunnon abstraction to characterize predicates. There are two features of this kind of abstraction which are important for the reconstruction of DRSs as predicates.

simultaneous abstraction Any number of parameters in a parametric object may be abstracted over simultaneously. While in standard λ-notations one may have expressions such as

$$\lambda x, y, z[\phi(x, y, z)]$$

this is to be construed as an abbreviation for

$$\lambda x[\lambda y[\lambda z[\phi(x, y, z)]]]$$

In Aczel-Lunnon abstraction, however, it is the set which is abstracted over. Thus arguments to the abstract can be supplied simultaneously and there is no required order.

indexing This feature is closely related to the previous one. Since abstraction over parameters results in an object in which those parameters do not occur[1], we have to have some way of

[1]This is important in order to achieve α-equivalence, i.e. $\lambda x[\phi(x)] = \lambda y[\phi(y)]$

determining how arguments are to be assigned to the abstract in the case where more than one parameter has been abstracted over. Aczel and Lunnon achieve this by defining the abstraction operation in terms of indexed sets of parameters, i.e. one-one mappings from some domain ("the indices") to the parameters being abstracted over. An important aspect of this for us is that we can use any objects in the universe as the indices.

The leading idea is that we model discourse representation structures as abstracts which from the situation theoretic perspective are predicates. If we are working in situation theory, modelling DRSs as predicates gives us two options. They can be either relations or types. The choice is illustrated in (1) with respect to DRS corresponding to *a man owns a donkey* (ignoring matters of tense).

(1) a. *Relation*

$$\begin{array}{|l|}\hline \quad i \rightarrow X,\ j \rightarrow Y \\ \hline \\ \text{man}(X) \\ \text{donkey}(Y) \\ \text{own}(X,Y) \\ \\ \hline \end{array}$$

b. *Type*

$$\begin{array}{|l|}\hline \quad i \rightarrow X,\ j \rightarrow Y,\ k \rightarrow S \\ \hline \boxed{S} \\ \\ \text{man}(X) \\ \text{donkey}(Y) \\ \text{own}(X,Y) \\ \\ \hline \end{array}$$

The difference is that in the relation there is no role for a situation whereas this is the case in the type. We will first consider the simpler option with DRSs as relations. We will then come to some motivation for considering them as types.

Note that whether we choose relations or types as the situation theoretic object to model DRSs we use roles of predicates (certain kinds of abstracts) to correspond to discourse referents. Thus we will talk of *discourse roles* rather than discourse referents, which represents a subtle shift in our view of what discourse representation is about.

2.1 DRSs as relations

This means that we will take (1a) as the relation corresponding to the DRS for *a man owns a donkey*. How now do we get the effect of non-selective existential quantification that is obtained when traditional DRSs are interpreted in a model? We cannot use interpretation in a model since our DRSs are not syntactic objects. However, abstracts are the kind of thing that can be quantified over using a variant of the same technique that is used for the introduction of quantification into the λ-calculus as represented in (2).

(2) $\exists(\lambda x[\phi(x)])$

We introduce a distinguished property of relations "instantiated" or "realized" represented by ∃. This holds of a relation just in case there is some assignment to the roles of the relation which yields something that holds true when the relation is applied to the assignment. We can make this precise in situation theoretic terms as in (3).

(3) $\begin{array}{|c|}\hline s \\ \hline \exists(r) \\ \hline \end{array}$ is true implies

there is some assignment f appropriate to r such that

$\begin{array}{|c|}\hline s \\ \hline rf \\ \hline \end{array}$ is true

If desired (3) could be strengthened to a biconditional, though I do not believe that this is necessary.

This shows us that, given the relation corresponding to the DRS for *a man owns a donkey*, we can construct an infon where this relation is existentially quantified.

(4)
$$\boxed{\exists\left(\begin{array}{|l|}\hline i \to X, j \to Y \\ \hline \text{man}(X) \\ \text{donkey}(Y) \\ \text{own}(X,Y) \\ \hline \end{array}\right)}$$

Notice the important effect of unselective binding here. Since we are using simultaneous abstraction we have simultaneous quantification. This is one important ingredient which enables us to capture the classical DRT analysis of donkey anaphora, though we will not have space in this paper to present the details.

Now that we have a quantified infon it is straightforward to use this to construct a proposition which might correspond to the interpretation of a DRS in classical DRT. If one does this in situation theoretic terms one such proposition is (5).

(5)
$$\begin{array}{|c|}\hline s \\ \hline \exists\left(\begin{array}{|l|}\hline i \to X, j \to Y \\ \hline \text{man}(X) \\ \text{donkey}(Y) \\ \text{own}(X,Y) \\ \hline \end{array}\right) \\ \hline \end{array}$$

But how are we going to achieve the effect of discourse anaphora if the DRS that you construct for a single sentence is modelled as an abstract where everything is already bound? It is here that the second feature of Aczel-Lunnon abstraction that I highlighted comes into play. The use of arbitrary role indices allows us to bind parameters but at the same time uniquely identify the roles in the abstract and identify roles across different abstracts. In designing grammars the strategy that I have been using for the incrementation of discourse representation is to assign a predicate corresponding to a DRS to each new sentence of the discourse and then integrate that predicate with the one obtained for the discourse so far. Basically the integration is predicate conjunction where roles that have the same index are merged. We define an operation of predicate conjunction, $\oplus$, which will be the central tool used in the incrementation of one DRS with another DRS (corresponding to the next sentence in the discourse).

The idea is best illustrated first by an example.

(6)
$$\begin{array}{|l|}\hline \quad i \to X,\ j \to Y \\ \hline \\ r(X,Y) \\ \\ \hline \end{array} \quad \oplus \quad \begin{array}{|l|}\hline \quad i \to W,\ k \to Y \\ \hline \\ r'(W,Y) \\ \\ \hline \end{array}$$

$$= \begin{array}{|l|}\hline \quad i \to X,\ j \to Y,\ k \to Z \\ \hline \\ \begin{array}{|l|}\hline \quad i \to X,\ j \to Y \\ \hline \\ r(X,Y) \\ \\ \hline \end{array} \quad \begin{bmatrix} i \to X \\ j \to Y \\ k \to Z \end{bmatrix} \\ \\ \begin{array}{|l|}\hline \quad i \to W,\ k \to Y \\ \hline \\ r'(W,Y) \\ \\ \hline \end{array} \quad \begin{bmatrix} i \to X \\ j \to Y \\ k \to Z \end{bmatrix} \\ \\ \hline \end{array}$$

$$= \begin{array}{|l|}\hline \quad i \to X,\ j \to Y,\ k \to Z \\ \hline \\ r(X,Y) \\ r'(X,Z) \\ \\ \hline \end{array}$$

In (6) we have two binary predicates which are conjoined by $\oplus$ to form a ternary predicate. The roles indexed by i in the two original predicates are merged in the result. If there had been no overlap in the indices the result would have been a quaternary predicate and if the roles of both binary predicates had been indexed by i and j then the result would have been a binary predicate. Thus even though the parameters are bound, the indices are freely available and can be used to encode anaphoric relations. Note that it is important here that we are allowing arbitrary indices rather than, say, always using an intial segment of the natural numbers to do our indexing. It is the fact that we are allowed to use arbitrary indices which will give us the freedom to use them to encode discourse anaphoric relations.

Given the machinery for Aczel-Lunnon abstraction we have sketched here it is quite straightforward to give a general definition of $\oplus$.

(7) **Definition of $\oplus$**

If ζ is a predicate with role indices $r_{\zeta 1}, \ldots, r_{\zeta n}$, ξ is a predicate with role indices $r_{\xi 1}, \ldots, r_{\xi m}$ and f is an assignment whose domain $\{r_1, \ldots, r_k\} = \{r_{\zeta 1}, \ldots, r_{\zeta n}\} \cup \{r_{\xi 1}, \ldots, r_{\xi m}\}$ which assigns a unique parameter X_i (which is distinct from any free parameter in ζ or ξ) to each r_i in its domain then

$$\zeta \oplus \xi = \begin{array}{|l|} \hline r_1 \rightarrow X_1, \ldots, r_k \rightarrow X_k \\ \hline \zeta f \\ \xi f \\ \hline \end{array}$$

In Cooper 1993 I have characterized a basic DRT fragment based on part of the fragment defined in Kamp and Reyle 1993 including donkey anaphora, quantified sentences and relative clauses. In characterizing the fragment I exploit the fact that the use of Aczel-Lunnon abstraction allows us to use abstracts not only to recreate DRSs in the way I have presented here but also to combine that with the use of abstraction for compositional interpretation as in Montague's semantics.

2.2 DRSs as types

The basic motivation for DRSs as types can be seen as soon as we look at DRSs of the kind which Kamp uses in his paper to introduce basic DRT concepts. Consider example (8) which he discusses there.

(8) Last month a whale was beached near San Diego. Three days later it was dead.

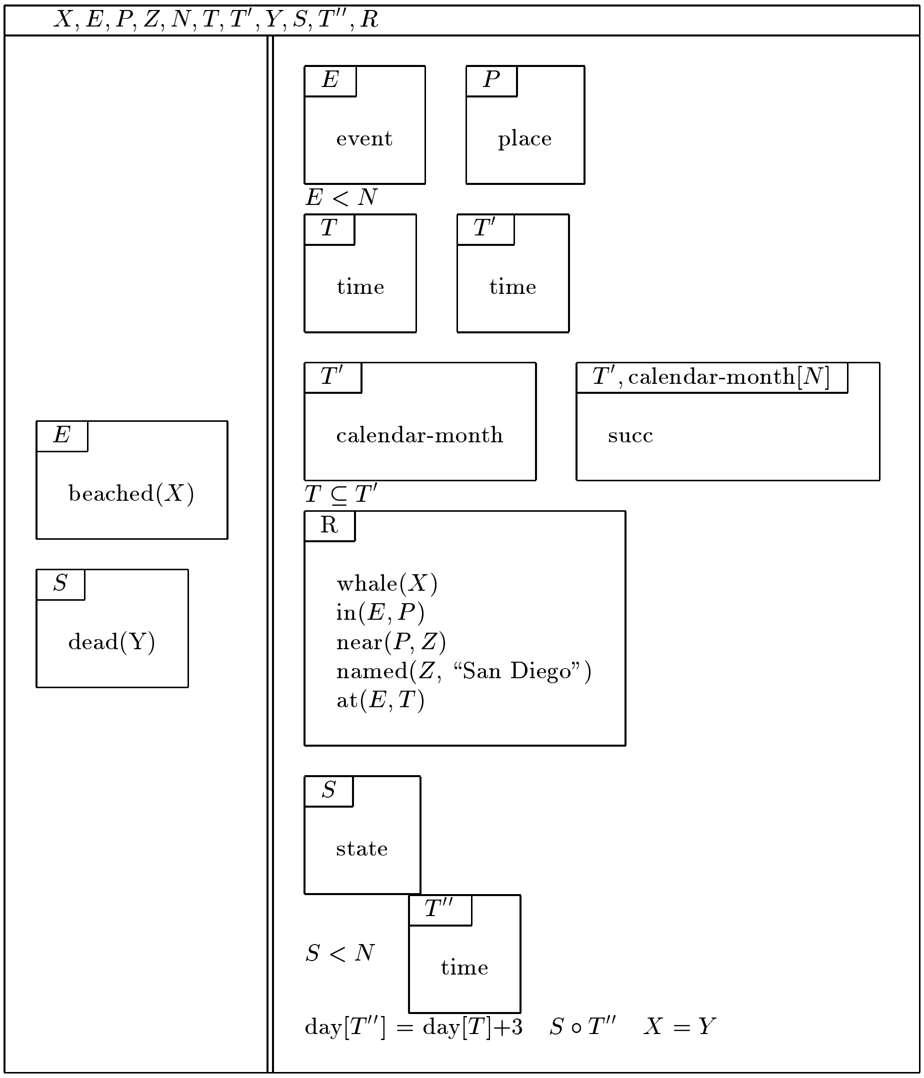
Kamp's DRS for the first sentence of (8) makes crucial use of a discourse referent for the event of the whale being beached and another discourse referent for the state of the whale being dead and there is a condition relating the temporal occurrence of the two. In his notation in the paper the relevant conditions look as in (9).

(9) a. $e \ldots \begin{array}{|c|} \hline \text{beached}(x) \\ \hline \end{array}$

b. $s \ldots \begin{array}{|c|} \hline \text{dead}(y) \\ \hline \end{array}$

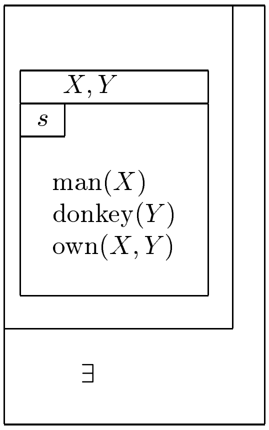
Often in DRS notations ':' is used instead of '...'. In (10) I give a rough reconstruction of Kamp's DRS for the discourse as a situation theoretic type. I have made many arbitrary decisions here, for example, concerning which information is backgrounded as restrictions and the exact representation of temporal relations. My only aim here is to illustrate the relationship between DRT's ':' or '...' and the situation theoretic notion of a situation supporting an infon.

(10)



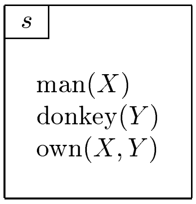
We can construct existential propositions from types in a similar manner as we did with relations.

(11)



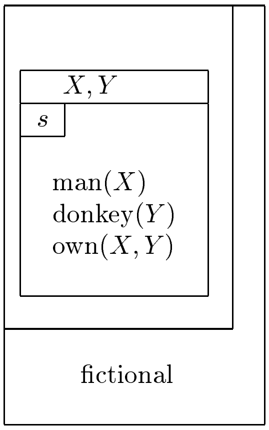
Barwise and Cooper 1991; Barwise and Cooper 1993 adopt the following notation for objects such as (11).

(12) $\exists X, Y$

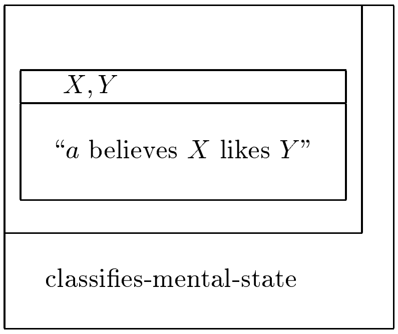


It is, however, important that we think of existential quantification as a predicate of predicates since this raises the possibility that we might construct propositions from DRSs that are other predicates of predicates for example *fictional* or, as becomes important when we talk of discourse referents linked between different agents, something like *classifies-mental-state*. Such predicates will not guarantee, of course, that the DRS is instantiated.

(13) a.



b.



3 Externally anchored DRSs

Kamp discusses the need for providing anchors for DRSs. The example he introduces is (14)

(14) That man is a cocaine dealer

External anchors can be modelled in the situation theory of Barwise and Cooper 1991 as assignments to role indices.

(15) $$< \begin{array}{|c||c|}\hline \multicolumn{2}{|c|}{1 \rightarrow X,\ 2 \rightarrow N,\ 3 \rightarrow S} \\ \hline \boxed{S} & \\ \text{cocaine-dealer}(X) & N \subseteq S \\ \hline \end{array} , \begin{bmatrix} 1 \rightarrow a \\ 2 \rightarrow t \end{bmatrix} >$$

4 Formally anchored DRSs

Kamp introduces the notion of a formal anchor in a DRS as a way of representing background beliefs which an agent might use to identify the objects which might be assigned to discourse referents. These can be modelled in situation theory as restrictions in the sense of Barwise and Cooper 1991.

(16) $$\begin{array}{|c||c|}\hline \multicolumn{2}{|l|}{X, N, S} \\ \hline \boxed{S} & \\ & N \subseteq S \\ \text{cocaine-dealer}(X) & \begin{array}{|c|}\hline \boxed{R} \\ V_1(X) \\ \vdots \\ V_m(X) \\ \hline \end{array} \\ & \\ \hline \end{array}$$

5 Mental states

Putting the two kinds of anchors together we have the view of belief represented by the infon in (17) where the belief relation holds between an individual, a type (representing the internal state of the agent), an assignment (representing the external connections of the internal state to the environment) and a time (at which the belief is held).

(17) $$\text{believe}(a, \begin{array}{|c||c|}\hline \multicolumn{2}{|c|}{X_1, \ldots, X_n} \\ \hline B & R \\ \hline \end{array} , \begin{bmatrix} i \rightarrow a_i \\ \vdots \\ m \rightarrow a_m \end{bmatrix}, t\ )$$

This view is essentially a modernized version of the proposal made by Barwise and Perry 1983; Barwise and Perry 1985. It is developed further and related to other proposals in the literature by Cooper and Ginzburg 1994. (17) is to be regarded as an infon which is supported by a situation which we will call a mental state. Thus we will have propositions such as (18) where *ms* is a mental state. We will sometimes refer the to the type as the *internal aspect* of the belief and the assignment as the *external aspect*.

(18)
$$\begin{array}{|l|}\hline \boxed{ms} \\ \text{believe}(a,\ \begin{array}{|c||c|}\hline \multicolumn{2}{|c|}{X_1,\ldots,X_n} \\ \hline B & R \\ \hline \end{array}\ ,\ \begin{bmatrix} i \rightarrow a_i \\ \vdots \\ m \rightarrow a_m \end{bmatrix},\ t\ ) \\ \hline \end{array}$$

6 Linking discourse roles

Kamp points out that it is important to be able to link discourse roles across different beliefs. This is an important insight which was not discussed at all in the earlier situation theoretic literature on belief. I will suggest here that we can do this by using the machinery of the λ-calculus. We will discuss the examples that Kamp discusses and follow him in considering first internal links between the beliefs of a single agent and then external links across roles in beliefs distributed across two agents.

6.1 Internal links

Let us first consider a type representing a DRS corresponding to the sentence *Mars is more massive than Venus.*

(19)
$$\begin{array}{|c||c|}\hline \multicolumn{2}{|c|}{\text{Mars} \rightarrow X,\ \text{Venus} \rightarrow Y,\ \ \text{desc} \rightarrow S,\ \ \text{res} \rightarrow R} \\ \hline \boxed{S} & \\ X \text{ is more massive than } Y & \begin{array}{|c|}\hline \boxed{R} \\ V_1(X) \\ \vdots \\ V_r(X) \\ W_1(Y) \\ \vdots \\ W_s(Y) \\ \hline \end{array} \\ \hline \end{array}$$

We will call the type in (19) p. Let us now consider a mental state corresponding to b's belief that a believes Mars is more massive than Venus.

(20)
$$\begin{array}{|l|}\hline \boxed{ms} \\ \text{believe}(b,\ \begin{array}{|c|}\hline \rho \rightarrow X \\ \hline \boxed{ms'} \\ \text{believe}(\ X, p, [\,], t) \\ \hline \end{array}\ ,\ [\ \rho \rightarrow a],\ t) \\ \hline \end{array}$$

(For more discussion of the treatment of embedded belief see Cooper and Ginzburg 1994.)

Now let us consider a type that would correspond to the internal aspect of a belief that Mars is more massive than Venus and that a believes that Mars is more massive that Venus.

(21)

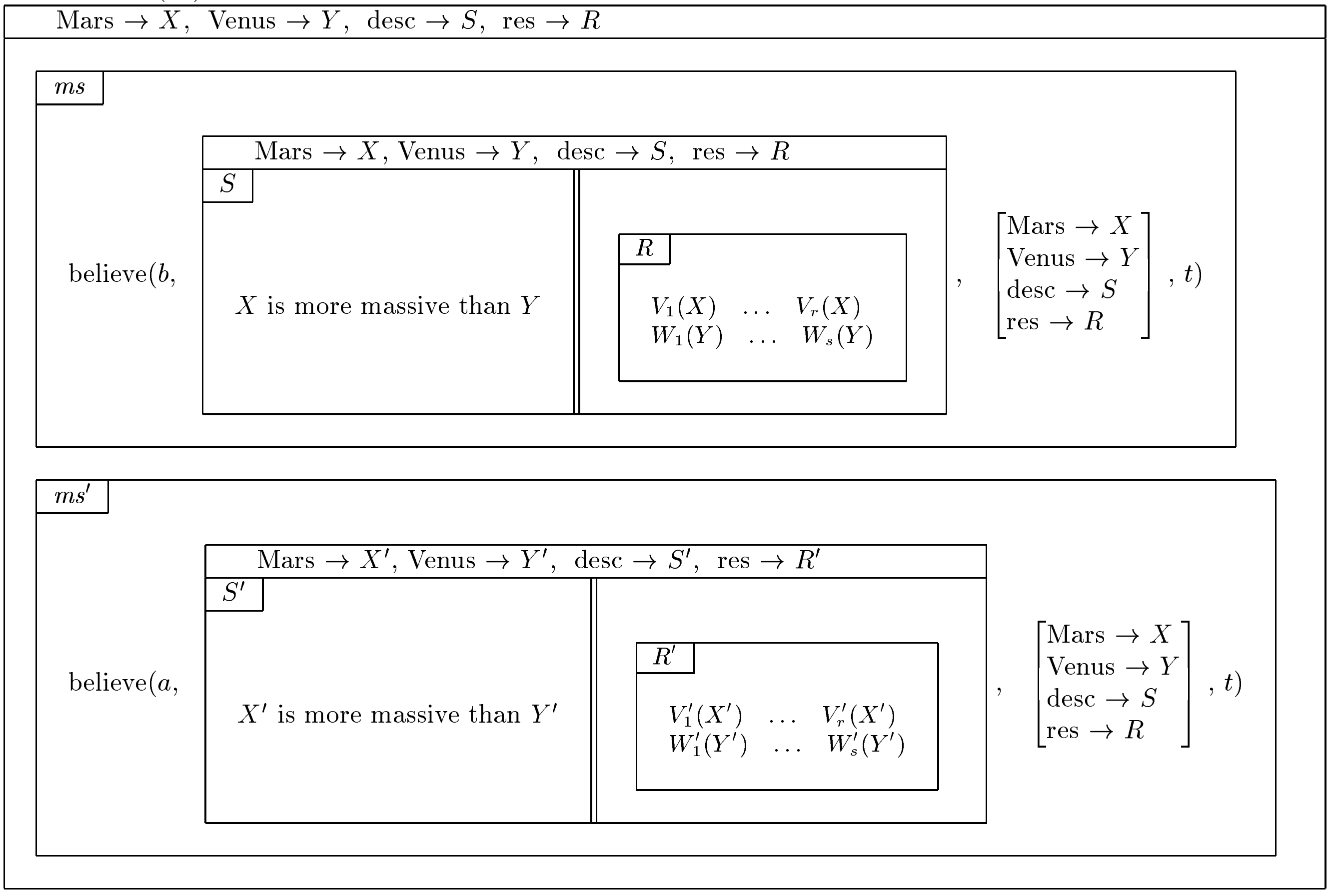
$$
\begin{array}{|l||c|}
\hline
\multicolumn{2}{|l|}{\text{Mars} \rightarrow X,\ \text{Venus} \rightarrow Y,\ \text{desc} \rightarrow S,\ \text{res} \rightarrow R,\ \rho \rightarrow Z} \\
\hline
\begin{array}{l}
\boxed{\begin{array}{l} S \\ X \text{ is more massive than } Y \end{array}} \\
\\
\boxed{\begin{array}{l} ms' \\
\text{believe}(Z, \begin{array}{|c||c|}
\hline
\multicolumn{2}{|c|}{\text{Mars} \rightarrow X', \text{Venus} \rightarrow Y',\ \text{desc} \rightarrow S',\ \text{res} \rightarrow R'} \\
\hline
\begin{array}{l} S' \\ X' \text{ is more massive than } Y' \end{array} & \boxed{\begin{array}{c} R' \\ V_1'(X') \\ \vdots \\ V_r'(X') \\ W_1'(Y') \\ \vdots \\ W_s'(Y') \end{array}} \\
\hline
\end{array}, \left[\begin{array}{l} \text{Mars} \rightarrow X \\ \text{Venus} \rightarrow Y \\ \text{desc} \rightarrow S \\ \text{res} \rightarrow R \end{array}\right], t
\end{array}}
\end{array}
&
\boxed{\begin{array}{c} R \\ V_1(X) \\ \vdots \\ V_r(X) \\ W_1(Y) \\ \vdots \\ W_s(Y) \end{array}} \\
\hline
\end{array}
$$

Here it is important to notice that the roles for Mars, Venus and the resource and described situations are linked. That is, if b has (21) as the internal aspect of a belief, then it represents something stronger than simply a belief that Mars is more massive than Venus and that a believes that Mars is more massive than Venus. In addition it represents the fact b believes that a's belief is connected to the same objects in the world, despite that fact that a may have different roles and different ways of indentifying the objects (i.e. different restrictions or internal anchors). The linking is achieved here by exploiting a standard λ-calculus technique for making things fall together. An example in the traditional λ-calculus would be $\lambda z[\lambda x, y[f(x, y)](z)(z)]$ where the "x and y roles" have been made to fall together into a single "z role". In (21) we have used an assignment to supply the roles in a's belief with parameters which are abstracted over in b's belief.

6.2 "External" sharing of discourse roles (Distributed belief)

I believe that this technique can be generalized to give an account of the external sharing of discourse roles cross different agents which, as Kamp points out, is important for the treatment of intensional identity as in Geach's well-known Hob-Nob examples. Following Kamp's discussion we will illustrate this linking by developing the previous examples concerning Mars and Venus.

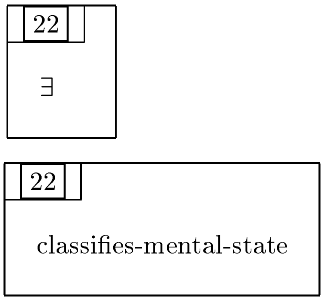
(22)



(22) could be used, for example, to represent the internal aspect of c's belief that a and b have linked beliefs about Mars and Venus (or as in Geach's original example, about a witch) without making a committment to c's belief being anchored to anything in the world, for example, if (22) is associated with the empty assignment in c's mental state. Alternatively, if we wish to use (22) to obtain the content of an assertion rather than a mental state without committing ourselves to the existence of anchors for the roles we could consider creating a proposition out of the type by using something other than the standard existence predicate in (23a). For example, (23b), might be used to indicate that (22) classifies a mental state distributed over a and b.

(23) a.

b.



7 Mutual belief

We give here a brief illustration of how mutual belief might be treated using non-well-founded situation theoretic objects along the lines suggested in Barwise 1989. The idea is that the type in (24) is labelled by p and that p is referred to itself within the type

(24)

Mars $\to X$, Venus $\to Y$, desc $\to S$, res $\to R$

ms

believe(b, [Mars $\to X$, Venus $\to Y$, desc $\to S$, res $\to R$ | S: X is more massive than Y ‖ R: $V_1(X) \;\ldots\; V_r(X)$, $W_1(Y) \;\ldots\; W_s(Y)$] , $\begin{bmatrix}\text{Mars} \to X\\ \text{Venus} \to Y\\ \text{desc} \to S\\ \text{res} \to R\end{bmatrix}$,t)

believe(b,p, $\begin{bmatrix}\text{Mars} \to X\\ \text{Venus} \to Y\\ \text{desc} \to S\\ \text{res} \to R\end{bmatrix}$,t)

believe(a, [Mars $\to X$, Venus $\to Y$, desc $\to S$, res $\to R$ | S: X is more massive than Y ‖ R: $V_1(X) \;\ldots\; V_r(X)$, $W_1(Y) \;\ldots\; W_s(Y)$] , $\begin{bmatrix}\text{Mars} \to X\\ \text{Venus} \to Y\\ \text{desc} \to S\\ \text{res} \to R\end{bmatrix}$, t)

believe(a, p, $\begin{bmatrix}\text{Mars} \to X\\ \text{Venus} \to Y\\ \text{desc} \to S\\ \text{res} \to R\end{bmatrix}$,t)

$\{p\}$

8 Conclusion

In this paper we have shown how discourse representation can be modelled in terms of situation theoretic objects and how this leads us to an account of the attitudes which points to the close relationship between proposals in situation semantics and in discourse representation theory. This seems to be a promising line of research not only because it points to parallels in apparently diverging theories but because the two approaches to the attitudes have contributions to make to each other. The linking of discourse roles is something that has been discussed previously in DRT but not in situation semantics. On the other hand the use of situation theoretic objects to represent the objects of attitudes seems more attractive than the essentially syntactic analysis that is suggested by the discourse theoretical approach. Also the fact that situation theory takes into account non-well-founded objects offers the promise of combining the approach taken here with an account of mutual belief.

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