The Treatment of Tense in Situation Semantics[1]

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In this paper, the four classical issues involving definite or dynamic interpretations of tense are first reviewed, as discussed in Hinrichs (1987). Then, an attempt is made to solve them in a situation-theoretic framework ã la Barwise (1989) with the notions of described, discourse, resource or background situations. For semantic composition, Yoo and Lee's (1988) equation solving approach is adopted to treat Hinrichs's tensed sentences. Finally, described and discourse situations are differentiated by the notions of temporal localization, connectedness, and dynamicity to state cons-traints on discourse situations and then properly to induce the dynamic or rational interpretation of a discourse.

0. Introduction

In this paper, I claim that Nerbonne's (1983) or Hinrichs's (1987) Reichenbachian or indexical approach to the interpretation of temporal expressions[2] is a particular application of Barwise and Perry's (1983) or Barwise's (1989) Situation Theory to the model-theoretic semantics of temporally constrained natural language. In order to account for definite interpretations of tense, as illustrated by 'Sam forgot to turn off the stove,' for in-

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[2] Nerbonne's (1983) dissertation was, I think, one of the first general attempts to introduce Reichenbach's (1947) tripartite notion of speech, event, and reference times into the construction of a compositional model-theoretic semantics for interpreting tensed statements or discourses in natural langauge.

stance, the indexical approach adopts Reichenbach's (1947) tripartite distinction of time as speech, event, and reference times, whereas the situation-theoretic approach utilizes the notion of described, discourse, resource or background situations. On the basis of these situations, various uses of temporal as well as indexical or quantificational expressions are compositionally interpreted with appropriate inferences.

In an attempt to support my claim, I will first take up the four basic issues involving definite or dynamic interpretations of tense that have been discussed in Hinrichs (1987). Then, I will briefly introduce some basic notions of Situation Theory and show how these problems can be accommodated in a situation-theoretic framework.[3] By adopting Yoo and Lee's (1988) equation solving approach to semantic composition, I will also sketch without going into any formal details how the meaning or information structure of tensed statements can be compositionally built up. Finally, I will also introduce some situation-theoretic notions to accommodate dynamic interpretations in a discourse.

1. Hinrichs's Treatment

Hinrichs (1987) adopted Reichenbach's (1947) notions of speech time, event time, and reference time to enrich Prior's (1967) or Montague's (1973) classical tense logic. On the basis of these parameters, he constructed tense logic with multiple indices, thus solving some of the crucial problems of tense which were first raised by Partee (1973) and then extensively discussed by Nerbonne (1983) and others, but which Prior's tense logic and Montague Semantics have failed to treat properly. The first such problem concerns the interaction between tense and negation.

1.1. Tense and Negation

According to a PTQ-type grammar, sentence (1) should be translated either into (2) or (3):

[3] Cooper (1986) was really the first to treat tense and discourse in Situation Semantics in an extensive manner, although an earlier attempt was made in Barwise and Perry (1983).

(1) Vincent did not leave.
(2) $\neg$Pleave′(Vincent′)
(3) P$\neg$leave′(Vincent′)

But neither translation is acceptable, for they both yield wrong interpretations. (2) says that Vincent has never left, while (3) says that at least once in the past Vincent didn't leave. But intuitively (1) is expected to mean that Vincent was supposed to leave at a certain period of time and didn't leave then.

To remedy this problem, Hinrichs relativizes the truth condition of a tensed statement with respect to refence time *r* and event time *t* as shown below:

(4) $[\neg \text{Pleave}'(\text{Vincent}')]_{r,t}=T$ iff $[\text{Pleave}'(\text{Vincent}')]_{r,t}=F$
iff $[\text{leave}'(\text{Vincent}')]_{r,t'}=F$ for all times t′ such that
$t'<t$ and $t'\subseteq r$.

The truth definition (4) makes it possible to obtain the correct interpretation of (1) that at some particular time in the past Vincent didn't leave.

1.2. Tense and Time Adverbials

PTQ may again translate (5) into either (6) or (7), where **P** is the past tense operator and **Y** is the propositional operator for 'yesterday'.

(5) Vincent left yesterday.
(6) **PY**leave′(Vincent′)
(7) **YP**leave′(Vincent′)

But the interembedding of these two operators yields a wrong interpretation. (7), for instance, is satisfied even if Vincent left the day before yesterday, while (6) is interpreted as saying 'Vincent's leaving yesterday occurred once in the past'. But ordinarily we expect (5) to mean that Vincent left sometime during the period of yesterday. Hinrichs thus introduces the following truth conditions based on reference time as well as event time.

(8) $[\mathbf{P}p]_{r,t}=T$ iff $[p]_{r,t'}$ for some time t′ such that $t'<t$ and $\mathbf{t}'\subseteq\mathbf{r}$.
(9) $[\mathbf{Y}p]_{r,t}=T$ iff $[p]_{[DAY(ts)-1],t'}=T$.

(10) $[\mathbf{YP}\text{leave}'(\text{Vincent}')]_{r,t} = T$
iff $[\mathbf{P}\text{leave}'(\text{Vincent}')]_{[DAY(ts)-1],t} = T$
iff $[\text{leave}'(\text{Vincent}')]_{[DAY(ts)-1],t'} = T$
for some $t' < t$ and $t' \subseteq [DAY(t_s)-1]$

According to (10), sentence (5) is taken to be understood as meaning that at some past time, but within yesterday Vincent left. This is obtainable because the event time t′ is contained by the reference time YESTERDAY or $[DAY(t_s)-1]$.

1.3. Tense and Quantified Noun Phrases

The scope of tense interacts with that of a quantified noun phrase as illustrated by (12) and (13).

(11) Every admiral was (once) a cadet.
(12) $\forall x[\text{admiral}'(x) \rightarrow \mathbf{P}[\text{cadet}'(x)]]$
(13) $\mathbf{P}[\forall x[\text{admiral}'(x) \rightarrow \text{cadet}'(x)]]$

But neither of the translations successfully captures the meaning of (11). The logical translation (12) is unacceptable because it fails to admit the past as well as the present admirals or to cut out a particular group of admirals: it just says that everyone who is an admiral now was a cadet at some time in the past. The logical translation (13) is worse because it is taken to say that at some time in the past every admiral was also a cadet, which would be an absurd situation.

To solve this problem, Hinrichs introduces the predicate **R**, which ranges over properties salient in a given context, and then presents the following translation for (11).

(14) $\forall x[\exists t[\text{admiral}'(x)(t) \wedge \mathbf{R}(x)(t)] \rightarrow [\exists t'[t' < t_s \wedge t' \in t_r \wedge \text{graduated-from}'(\text{Annapolis}')(x)(t')]]$

This formula, which looks rather complicated, is roughly taken to mean that everyone who was or is an admiral at some time and who has some salient property **R** in a given context, say the status of being assigned to a particular post, has graduated from Annapolis. This solved both the problems of deciding the class of admirals and avoiding simultaneity imposed on admiralty and cadethood by (13).

1.4. Temporal Anaphora

Hinrichs also solves the problem of sequencing event times.

(15) [Vincent was hit by a harpoon]$_{e1}$, [abandoned by its crew]$_{e2}$, and [sank]$_{e3}$.

(16) $r_1 < r_2 < r_3$, where $e_1 \subseteq r_1$, $e_2 \subseteq r_2$, $e_3 \subseteq r_3$.

As represented in (16), the sequential interpretation is induced by the temporal order of reference times. Each event is understood as taking place in the temporal order as is mentioned sequentially in the sentence.

I have briefly reviewed four of the problems involving tense and Hinrichs's solutions. But I intend to show that Situation Semantics can offer equally acceptable but perhaps more elegant solutions to the same problems.

2. Situation-theoretic Approach

Adopting the Austinian approach to meaning, Situation Semantics takes the notion of *situation* seriously and views a *proposition* consisting of both propositional and descriptive content. First, a typical proposition has the following form:

(17) $(s \models \sigma)$

where s is a situation; σ, an infon which carries basic information about the situation s; and $\models$, a *supports* relation between them. This proposition is true, if the infon σ is a fact supported by the situation s; otherwise, it is false.

The notion of *described situation*, or subject matter, plays an important role in distinguishing the content of a proposition. Suppose we query whether YS Kim was newly elected President. Then, the answer varies according to what we are talking about.[4] If we are talking about the result of the 1992 presidential election in Korea, then the answer is definitely 'Yes';

[4] The answer will also vary according to when the query is made. But we ignore this fact for the moment.

whereas, if we are talking about the 1987 election, then the answer should be 'No'. But what if we are talking about the Presidential elections in the United States. then the answer will be simple: no one can simply say 'Yes' or 'No' without adding some comment, for Kim did not run for that election at all. It can thus be noticed that the question whether YS Kim was elected President is variously interpreted.

Suppose we make a claim that YS Kim was elected President. This claim again has a different content, depending on what is being talk about, although the core content of what is being uttered remains the same. The core content called a *descriptive content* is the information or fact that YS Kim was elected, while the entire claim called a *propositional content* carries a truth value, truth or falsity depending on its subject matter or described situation. Here are two different propositional claims with the same descriptive content, as represented below:

(18) $s \models \langle\langle \text{elected-president, YSKim; } 1 \rangle\rangle$

(19) $s' \models \langle\langle \text{elected-president, YSKim; } 1 \rangle\rangle$

where s is the situation of the 1992 presidential election in Korea and s′, that of the 1987 presidential election in Korea. As it was the case that happened, (18) is true, whereas (19) is false, for YS Kim won the 1992 election, but lost the 1987 election to President Roh. In other words, the fact that YS Kim was elected President is supported by the situation s, but is not supported by s′.

The notion of *background* as a type of situation also plays an important role in interpreting informational as well as propositional content. Suppose the new ambassador from Tibet believed that DJ Kim was YS Kim. Then the claim made by a statement 'YS Kim was elected President' will be false, even if its described situation is the 1992 presidential election. This distinction can be captured by introducing a *restricted parameter*, $x^{p(x)}$ or $x \mid p(x)$, an indeterminate x restricted by a parametric proposition $p(x)$.[5] With this notion, some person who is believed to be YS Kim can be represented as below:

(20) $x^{(S_b \models \langle \text{named}, x, \text{YSKim}; 1 \rangle)}$

or

$x \mid (s_b \models \langle\langle \text{named}, x, \text{YSKim}; 1 \rangle\rangle)$

[5] Instead of introducing a restricted parameter, we can introduce the notion of a *restricted infon* of the form: $\sigma(x) \mid p(x)$.

We also have then:

(21) s $\models$ 《elected–president, $x^{(S_b \models \langle \text{named}, x, \text{YSKim}; 1 \rangle)}$; 1》

Unlike the propositional claim (18), this new proposition is sensitive to the background belief. If someone like the Tibetan ambassdor has a wrong belief, he will believe that YS Kim was not elected President. On the other hand, if someone has the right belief and that belief is the background s_b in (21), then the claim (21) is true. Hence, the situation–theoretic semantics makes the interpretation of a proposition sensitive to its background as well as to its subject matter.

Situation Semantics emphasizes the efficiency of language as a tool for human communications. As such, language is full of indexical expressions the interpretation of which depends on the context of its use. This context is called a *discourse situation*. This situation provides information about the speaker, the hearer, the utterance time and place and so on necessary for interpreting such indexcial expressions as 'I', 'you', 'now' and 'here'.

Finally, a *resource situation* defines the domains which quantifier expressions range over. Consider the following:

(22) Every student is asleep.

By this statement, we hardly talk about every student at any time and at any place, but rather restrict out attention to a group of students under the current discussion. This restriction is effected by defining a *type* as a property restricted by a parametric proposition, as represented below:

(23) $[x \mid p(x)]$

Then, the infon carried by (22) is represented as:

(24) 《every, $[x \mid$ ($s_r \models$ 《student, x; 1》)], asleep; 1》

This is defined to be a fact, if every individual who is a student under the resource circumstances s_r is alseep.

Note here that we can also restrict the property of being asleep. Suppose that yesterday, while observing Mr, Lee's class, Mr Kim made a statement about someone being asleep during yesterday's class. Then, the type of being asleep during yesterday's class will be represented as:

(25) $[x \mid$ (yesterday's class $\models$ 《asleep, x;1》)]

The resource situation s_r may not be the same as the resource situation of yesterday's class. Mr. Kim might have sent his own students to Mr. Lee's class and observed how they were doing in his class. He might have noticed that Lee's students were all alert, while every one of his own students was asleep. In this situation, he could appropriately asssert that every student (of his) was asleep, by saying 'everyone student is asleep' or even 'everyone is alseep'.

In order to compositionally treat the analysis of tensed sentences, I adopt an equational approach through which the information structure of each expression, basic or complex, is represented as a set of infon equations. The imformation structure of a complex expression is then obtained by unifying and solving the equation sets of its constituent expressions.

For simple illustration, consider:

(26) Kim snores.

The information structures of 'Kim' and 'snores' are first represented as below:

(27) a. Kim: $x=x' | (s_b \models \langle\langle named, x', Kim; 1\rangle\rangle)$
or simply, x_{kim}
b. snores: $\sigma = \langle\langle snores, x; 1\rangle\rangle$

Then, by unifying these two equations, we get:

(28) Kim snores: $\sigma = \langle\langle snores, x_{kim}; 1\rangle\rangle$

Suppose that this sentence is used as a statement describing a situation s. Then, we interpret such a statement as making a proposition with its descriptive content σ, as is represented in (28). And this proposition of

(29) $s \models \langle\langle snores, x_{kim}; 1\rangle\rangle$

is to be true if the infon $\langle\langle snores, x_{kim}; 1\rangle\rangle$ holds in the described situation s.

Having briefly introduced several types of situation and an equational way of treating information structures, I shall now discuss the four problems of tense that have been discussed in section 1.

2.1. Tense and Negation

There are two types of infon, positive and negative. A positive infon carries positive information, and a negative infon, negative information. For example, given polarity values 1 and 0, the positive infon 《snores, x_{kim}; 1》 may have as its dual a negative infon 《snores, x_{kim}; 0》. Provided that the world is a maximal coherent situation and that its parts are also situations, we assume that no identical situation supports both a positive infon σ and its dual $\bar{\sigma}$. But it is possible that a situation may support neither σ nor its dual $\bar{\sigma}$. Suppose we have not even begun counting election returns. Then, at this situation s, we can confirm neither YS Kim's winning the Presidential election nor his losing it. So, we have:

(30) a. s $\not\models$ 《elected-president, YSKim; 1》
b. s $\not\models$ 《elected-president, YSKim; 0》

Now, consider the following negative sentence:

(31) Vincent didn't leave.

This sentence consists of three words or basic expressions. In the Lexicon, it is assumed that their information structures are provided.

(32) Lexicon:
a. leave: σ=《leave, x, t; 1》
b. didn't: $\tau = \bar{\sigma}$
$t = t' \mid (s_r \models$ 《precedes, t', t_s; 1》), or simply $t = t_{r-past}$
$t_s = t'' \mid (s_d \models$ 《utters, $x_{speaker}$, (31), t''; 1》)
c. Vincent: $x = x' \mid (s_b \models$ 《named, x', Vincent; 1》, or simply $x = x_{vincent}$

The items (a) and (c) are simple enough: the verb 'leave' carries the information that it is a relation between its agent x and its event time t, while the name 'Vincent' contains the information that it can be any individual object who is supposedly named Vincent.

But the negative auxiliary verb 'didn't' contains a complicated piece of information. It first provides the dual $\bar{\sigma}$ of the information content σ of the main verb to which it is adjoined. Secondly, it provides temporal information: the event time t is the restricted past time t_{r-past}, namely the time t' which precedes the time t_s but is restricted by a resource situation s_r. Here, the time t_s is a speech time defined by the discourse situation s_d: it is the time at which the speaker utters the sentence (31). Notice that the time t is not ANY past period of time, but a parametric time the anchoring of which is restricted by the condition that its preceding of the speech time t_s is supported by a resource situation. Since a resource situation normally cuts out a domain over which the anchoring of parameters ranges, the temporal parameter t′ in [32] above will be anchored to a particular period or moment of time within that domain, thus allowing its definite or restrictive interpretation.

By unifying the sets of equations in (32), we now obtain:

(33) Vincent didn't leave: $\tau = \langle\langle \text{leave}, x_{vincent}, t_{r-past}; 0 \rangle\rangle$

The infon τ is the result of first replacing the positive polarity 1 in the infon σ of 'leave' with the negative polarity 0 and then substituting the parameters x and t in it with the restricted parameters $x_{vincent}$ and t_{r-past}, respectively. Here, the individual parameter $x_{vincent}$ is restricted by a condition characterized by a background or belief situation, while the temporal parameter t_{r-past} is restricted by conditions characterized by a discourse situation s_d and a resource situation s_r

Finally, sentence (31) can be used to describe a situation s. Then, the claim made by such a statement will express a proposition as represented below:

(34) $s \models \langle\langle \text{leave}, x_{vincent}, t_{r-past}; 0 \rangle\rangle$

Its descriptive content is Vincent's not having left at the time t_{r-past} and if it is a fact describing the situation s and supported by it, then the proposition is true; otherwise, it is a false claim.

2.2. Tense and Time Adverbials

As in Hinrichs (1987), time adverbials like 'today' and 'yesterday' are both treated as defining a certain interval of time t′ that contains at least one subinterval t, which may not be necessarily different from t′ itself. But they each point to a distinct time interval. Here are some illustrations:

(35) today:

$$t \subseteq t'$$

$$t' = t'' \mid (s \models [\langle\langle \text{day}, t''; 1 \rangle\rangle \wedge \langle\langle \text{contains}, t'', t_s; 1 \rangle\rangle])$$

$$= t_{today}$$

(36) yesterday:

$$t \subseteq t'$$
$$t' = t'' \mid (s \models [\langle\langle day, t''; 1\rangle\rangle \wedge \langle\langle precedes, t'', t_{today}, 1_{day}; 1\rangle\rangle]) = t_{yesterday}$$

Now, the past-tensed verbs like 'left' are assigned an information structure, as is illustrated below:

(37) left: $\sigma = \langle\langle leave, x, t; 1\rangle\rangle$
$$t = t_{r-past}$$

By combining the verb 'left' with a temporal adverb 'yesterday, we obtain a verb phrase 'left yesterday' with its information structure as is represented below:

(38) left yesterday: $\sigma = \langle\langle leave, x, t_{r-past} \mid (t_{r-past} \subseteq t_{yesterday}); 1\rangle\rangle$

The above equation is obtained by substituting $t_{r-past} \mid t_{r-past} \subseteq t_{yesterday}$ for t. Because of this restriction, the anchoring of t_{r-past} is restricted to the interval defined by $t_{yesterday}$. Likewise, we can obtain the information equation of 'left today':

(39) left today: $\sigma = \langle\langle leave, x, t_{r-past} \mid (t_{r-past} \subseteq t_{today}); 1\rangle\rangle$

Here, again the anchoring of the resource-restricted past temporal parameter t_{r-past} is restricted to a temporal range t_{today}.

While (39) is interpretable, the verb phrase 'left tomorrow' is uninterpretable.

(40) left tomorrow: $\sigma = \langle\langle leave, x, t_{r-past} \mid (t_{r-past} \subseteq t_{tomorrow}); 1\rangle\rangle$

This is so, because no anchor of t_{r-past} can be contained in the interval $t_{tomorrow}$, thereby failing to satisfy the condition that $t_{r-past} \subseteq t_{tomorrow}$, where $t_{tomorrow}$ is defined as $t'' \mid (s \models [\langle\langle day, t''; 1\rangle\rangle \wedge \langle\langle follows, t'', t_{today}, 1_{day}; 1\rangle\rangle])$. Note that t_{r-past} is some temporal point preceding a speech time t_s, that this speech time is contained in t_{today}, and that no point of $t_{tomorrow}$ is contained in t_{today}. Hence, t_{r-past} cannot be anchored to any point in $t_{tomorrow}$.

Now, to obtain the information structure of 'Vincent left yesterday', we simply substitute $x_{vincent}$ for x in the information structure of 'left yesterday':

(41) Vincent left yesterday:

σ=《leave, $x_{vincent}$, t_{r-past}|($t_{r-past} \subseteq t_{yesterday}$); 1》

This sentence again can be used to make a statement about the ship named 'Vincent', claiming that it left yesterday, or the day before the statement is made. If the situation thus described is s, then the proposition will be of the form:

(42) (s $\models \sigma$)

where the descriptive content σ is an infon 《leave, $x_{vincent}$, t_{r-past}|($t_{r-past} \subseteq t_{yesterday}$); 1》. And the proposition will be true, if this infon is supported by the situation s.

2.3. Tense and Quantified Noun Phrases

As in Barwise and Cooper (1981), in this paper quantifiers will be treated as relations between two properties. A universally quantified sentence, for instance, will be of the form 《every, P_1, P_2; 1》, carrying the information that a set having the property P_1 is a subset of a set having the property P_2.

Consider a more concrete example:

(43) Every man snores.

(44) 《every, man, P_2; 1》

A basic property **man** is the first argument of **every**, where P_2, its second argument, is a complex property [x|《snores, x; 1》].[6] The information conveyed by the assertive use of (43) or carried by the infon (44) is factual, in case that, for any object x, the infon 《man, x; 1》 involves an infon 《[x|《snores, x; 1》], x; 1》. Note here that 《[x|《snores, x; 1》], x; 1》 is logically equivalent to 《snores, x: 1》 by reduction.

Let's now discuss Hinrichs's example:

(45) Every admiral was a cadet.

This sentence may be interpreted as saying that, if someone was or is an

[6] In general, a complex property [x|σ(x)] is formed by abstracting over a parametric infon σ(x) by binding the parameter x. A type [x|p(x)], which is a particular sort of property, may also be formed by abstracting over a parametric proposition p(x) by binding the parameter x.

admiral, then he had or has been a cadet. First, by making use of the notion of resource situation, we can treat the property of being admiral as a type sensitive to its temporal location t the anchoring of which is restricted by a resource situation s_r:

(46) admiral: $P_1=[x \mid (s_r \models \langle\langle admiral, x, t; 1\rangle\rangle)]$

Here, the domains over which the parameters x and t range will be restricted by the resource situation s_r. thus, depending on a particular resource situation, all the admirals under the present discussion are only those present in this room right now.

Secondly, by introducing a resource restricted temporal location to the complex property of a verb phrase 'was a cadet,' as in (47), we can allow a definite interpretation of the past tense.

(47) was a cadet: $P_2=[y \mid \langle\langle cadet, y, t_{r-past}; 1\rangle\rangle]$

But to capture the fact that one must have been a cadet prior to his being promoted to admiralty, this fact must be encoded in an interpretation mechanism. Since this is a piece of world knowledge, it can be treated simply as part of background for the processing of information.

(48) $s_b \models (\langle\langle involves, (\sigma(t) \wedge \tau(t')), \langle\langle precedes, t', t; 1\rangle\rangle),$
where
$\sigma(t)=\langle\langle [x \mid (s_r \models \langle\langle admiral, x, t; 1\rangle\rangle)], x; 1\rangle\rangle$
$\tau(t')=\langle\langle [y \mid \langle\langle cadet, y, t'_{r-past}; 1\rangle\rangle], x; 1\rangle\rangle$

While cadethood must temporally precede admiralty, there is no such requirement between admiralty and professorship.

(49) Every admiral here was a professor at the Naval Academy.

This statement does not entail that one was a professor before his becoming an admiral; one could have taught at the Naval Academy even after he was appointed admiral. Hence, the constraint (48) simply reflects part of the Naval promotion system.

In Situation Semantics, constraints like (48) play an important role in processing information. Sentences are not interpreted without their contexts of use. And these contexts consist of knowledge or belief background, impact from the preceding utterances in the discourse, the speaker's intention, and so on. The truth–value of the proposition expressed by the sentence 'every admiral was a cadet' depends on the context of its use, and particularly on the constraint like (48). Because of this constraint, we know that every admiral, present or past, was once a cadet; otherwise, we don't.

2.4. Temporal Anaphora

In treating temporal anaphora, we also have to rely on various constraints on the temporal structure of a discourse. Consider again Hinrichs's example:

(50) Vincent was hit by a Harpoon, was abandoned by its crew, and sank.

In order adequately to interpret the statement made by the sentence (50), one should know not only about the use of language, but also some facts about the world and the human mind. He should, for instance, know that in an ordinary narration the temporal order of events described matches the order of describing them. This discourse rule, indeed, applies to the interpretation of (50): The event of Vincent's being hit by a Harpoon occurred first, then was followed by the crew's abandoning it, and finally by its sinking. Thus, the temporal order of these events matches their descriptive order.

But besides this discourse rule, the language user must have some knowledge about the world and the process of human reasoning. Consider (50) again: the first event described by 'Vincent was hit by a Harpoon' must be understood as a *reason* for the crew's abandoning the ship and also as a *cause* for its sinking. Here, the reason for the crew's action was based on their perception of causality or cause–effect relation: the crew decided to abandon their ship, realizing that it was irreparably damaged by a Harpoon and would sink soon so that their lives would be endangered. These causal and reasoning processes are reflected in the flow of information, for causes precede effects and rational actions are caused by the perception of some upcoming events.

In this section, I will briefly sketch how these linguistic or world facts can be accommodated in a dynamic interpretation of discourse statements. For this, it seems to be in order here to introduce a few definitions that help characterize various types of situation. First, I define the notion of *subsituation*:

(51) A situation s′ is a *subpart* or *subsituation* of a situation s if s supports every infon σ suported by s′.

By this definition, we can subdivide the situation s, in which all the three events described by (50) occurred, into three subsituations s_1, s_2, and s_3, each supporting a distinct event. Suppose the subsituation s_1 supports an infon 《be–hit, $x_{vincent}$, $y_{harpoon}$; 1》. Then, this infon is also supported by s, since s_1 is its subpart.

Secondly, a basic infon of the form 《*r*, *a*, *t*; *i*》 is said to be *temporal* or *temporally localized*, where *r* is a relation, *a* is a (partial) function that assigns argument roles to the relation *r*, *t* is a temporal location, and *i* is a polarity value, either 1 or 0. A situation s is *temporal* or *temporally localized* if it supports a *temporal* or *temporally localized* infon. Given a temporally localized infon $\sigma_1(t_1)$, say 《be–hit, $x_{vincent}$, $y_{harpoon}$, t_1; 1》, a situation s_1 that supports $\sigma_1(t_1)$ is temporally localized.

Thirdly, a temporally localized situation s is *connected* at a time interval t, if it satisfies the following conditions.[7]

(52) Given any pair of subsituation s_i and s_j of s, and any pair of subintervals t_i and t_j of t such that $t_i < t_j$ or $t_i = t_j$,
[i] $s_i \models \sigma_i(t_i)$ and $s_j \models \sigma_j(t_j)$
[ii] $s \models \sigma_i(t)$ and $s \models \sigma_j(t)$[8]

Suppose that the three events described by (50) occurred at the time, t, say yesterday, and that each of them is supported by some situation s. Then we can find its subsituations s_1, s_2, and s_3 that support each infon $\sigma_1(t_1)$, $\sigma_2(t_2)$, and $\sigma_3(t_3)$, respectively, such that t_1, t_2, and t_3 are linearly ordered subinter

[7] Nerbonne (1986) made a distinction between temporally connected and free discourses. His definition of temporal connectedness is different from mine given here. He states that in connected discourse reference time is fixed, while it isn't in free discourse: the 'temporally connected discourse talks about the same time, while the free discourse does not.'

[8] Note first that $(s \models \sigma(t))$ does not entail that $(s \models \sigma)$ is true at every point or subinterval t′ of time in t. Ordinarily, it means that $(s \models \sigma)$ is true at some particular time in t. Hence, even if $s \models \sigma_1(t)$ and $s \models \sigma_2(t)$, it may not be that these infons are factual at the same particular period of time in t. Since Vincent was hit by a Harpoon at 10:00 a.m. yesterday and it sank at 2:30 p.m. yesterday, it is true that both of the events occurred yesterday, but not necessarily at the same time yesterday.

vals of the time yesterday, say 10:00 a.m., 2:00 p.m., and 2:30 p.m., respectively. The supersituation s that supports the entire series of (yesterday's) events described by (50) is thus connected.

An incoherent or contradictory situation is disconnected. Compare:

(53) Vincent wasn't sinking, but it was.

(54) Vincent wasn't sinking around 1: 00 p.m., but it was around 2:30 p.m..

Yesterday's situation may support both the events described by the clauses in (54). On the other hand, (53) creates a contradictory situation. Thus, there cannot be any situation yesterday that supports both Vincent's not sinking and sinking. The statement made by 'Vincent wasn't sinking (yesterday)' simply entails that there was no period of time yesterday during which Vincent was sinking.[9]

A discourse situation is connected normally. Consider a naval officer Lt. Brown reported yesterday's events at today's regular briefing session. Then his report that lasted for 15 seconds was connected: it took six seconds each to utter 'Vincent was hit by a harpoon' and 'abandoned by the crew' and only three seconds to utter 'and sank'. Even if he was interrupted by something and it took a minute to finish uttering the entire sentence (50), his report is still considered connected, for the report holds as such during the entire one-minute period of reporting and each subutterance supports the statement of each subevent at each subperiod of his utterance time.

The following discourse carried by Kim and Lee is also connected.

(55) Kim: Vincent sank.
Lee: No, it didn't.

During the discourse that lasted eight seconds with a three second pause, the role of speaker changed and the two speakers contradicted each other. So the described situation by this discorurse fails to satisfy the condition [ii] of (52) and is thus disconnected. But the whole discourse itself is connected, for it supports its subutterance situations throughout the period of eight seconds.

[9] In general, a temporally localized *positive* infon of the form ⟪r, **a**, t; 1⟫ is factual if ⟪r, **a**; 1⟫ is factual at *some* particular period of time in t, whereas a temporally localized *negative* infon of the form ⟪r, **a**, t; 0⟫ is factual only if ⟪r, **a**; 0⟫ is factual at *every* period of time in t or throughout t.

Fourthly, a temporally localized situation may be *dynamic* at time interval t, if the following conditions are satisfied:

(56) Given any pair of subsituations s_i, s_j of s, and any pair of subintervals t_i, t_j of t such that $t_i < t_j$,
[i] $s_i \models \sigma_i(t_i)$ and $s_j \models \sigma_j(t_j)$
[ii] $s \models \sigma_i(t)$ and $s_j \models \sigma_j(t)$

The definition of dynamicity is exactly the same as that of connectedness, except that the pair of subintervals are strictly ordered for dynamicity. This minute difference distinguishes the situations described by the following statements:

(57) Vincent was hit by a Harpoon and so were some of the crew.
(58) Vincent was hit by a Harpoon and some of the crew were killed (at the same time).
(59) Vincent was hit by a Harpoon and the crew abandoned it.
(60) Vincent was hit by a Harpoon and (then) sank.

The events described in (57) or (58) may have occurred simultaneously, while those in (59) or (60) are sequential events, one happening after the other. Hence, all the situations here are connected, but only the latter two are dynamic. Note that described situations may simply be connected but not dynamic, whereas dynamic utterance situations are always connected.

Having discussed how situations can be temporally localized and connected or dynamic, I now briefly discuss how causal knowledge or human reasoning can interact with the interpretation of tensed statements or temporally localized situations.

By an axiom that causes precede effects, causes are described before their effects in a connected or dynamic discourse. So we have:

(61) Vincent was hit by a Harpoon and sank.

Here, Vincent's being hit by a Harpoon is described first and then is its sinking. Accordingly, the former event is understood to be a cause for the latter. But the descriptive order can be ignored if the cause–effect relation is explicitly mentioned.

(62) Vincent sank because it was hit by a Harpoon.

Vincent's sinking is described here first, but understood as a result of its being hit by a Harpoon as described by the 'because'-clause.

But now consider:

(63) Vincent sank and was hit by a Harpoon.

Unlike (61), it is no longer possible to read form (63) the cause-effect relation between Vincent's being hit by a Harpoon and its sinking.

In parallel to (61) and (62), we have:

(64) Vincent was hit by a Harpoon. It sank.
(65) Vincent sank. It was hit by a Harpoon.

In (64), the order of description and the temporal order of the events described match each other, whereas in (65) they don't. Here, the discourse situations are disconnected, so the descriptive order need not match the temporal order of events described as is required in a connected discourse by the cause-effect axiom.[10] And it should be noticed that the situation in which a cause-effect relation holds is typically dynamic. Accordingly, the following rule may be formulated as a constraint on a discourse situation:

(66) Dynamicity
In a dynamic discourse that describes a dynamic situation the order of description must match the temporal order of events described.

Because of this constraint, the connective 'and' describing a dynamic situation is understood as a temporally sequential connective 'and then' or 'and next'.

As formulated in (66), the dynamicity constraint applies not only to a dynamic discourse describing a cause-effect relation between a pair of events, but also to those describing in which a series of events occur sequentially.

(67) Kim came home and got drunk.

[10] Lascarides and Asher (1989) have distinguished them by treating (64) as a narration and (65) as an explanation. They claim that in a narration the temporal order of events involving the cause-effect relation must match that of description, while in an explanation the order of description may be reversed.

There is no causal relation between the two events described by the sentence (67), but we understand that Kim came home and then got drunk. If we reverse the order of description, then the temporal order of the events will also be reversed.

(68) Kim got drunk and came home.

This sentence says that Kim got drunk before he came home.

Now, consider how the process of reasoning is reflected in a discourse.

(69) Vincent was hit by a Harpoon and the crew abandoned it.

This is another case illustrating how the constraint of dynamicity works. Here, a dynamic situation is described dynamically, but the first event wasn't necessarily the entire cause for the crew's abandoning the ship. The crew decided to leave the ship because they foresaw that the ship could not be saved, so their action here was caused by their perception of the current situation and its predictable consequence. This is well illustrated by a situation described by (70).

(70) Vincent was hit by a Harpoon, abandoned by its crew, and sank.

This fact can be captured by the following constraint on a discourse situation:

(71) Rationality

In a dynamic disocurse describing a dynamic situation in which an action precedes an event, the latter is understood as providing a reason for the former.

Compare the following:

(72) The driver got out of the car and it exploded completely.

(73) The car exploded completely and the driver got out of it.

It is possible that the two events described in (72) are not connected at all. But if they are, then the explosion of the car should be understood as a reason for the driver's getting out of it. This interpretation is obtained because of the rationality constraint above. The rationality constraint does not apply to (73), although the dynamicity constraint does: it is simply a miraculous situation, if such a situation is physically possible.

The compositional interpretation of Hinrichs's problematic sentence (15), which is repeated here as the sentence (75), is also possible. Here, I simply show how the information equations are unified to yield its entire information structure. In an adequate Lexicon, the following entries are listed:

(74) a. Vincent: $x = x_{vincent}$

b. was hit by a harpoon: $t_1 = t_{1r-past}$

$\sigma_1(t_1) = \langle\langle$be-hit, x, $y_{harpoon}$, t_1; $1\rangle\rangle$

C. abandoned by its crew: $t_2 = t_{2r-past}$

$\sigma_2(t_1) = \langle\langle$be-abandoned, x, x's crew, t_2; $1\rangle\rangle$

d. and: $(\sigma_i \wedge \sigma_{i+1})$

e. sank: $t_3 = t_{3r-past}$

$\sigma_3(t_i) = \langle\langle$sink, x, t_3; $1\rangle\rangle$

By unifying these equations, we then obtain:

(75) *Vincent was hit by a harpoon, abandoned by its crew, and sank*:

$(\sigma_1(t_{1r-past}) \wedge \sigma_2(t_{2r-past}) \wedge \sigma_3(t_{3r-past}))$

$\sigma_1(t_{1r-past}) = \langle\langle$be-hit, $x_{vincent}$, $y_{harpoon}$, $t_{1r-past}$; $1\rangle\rangle$

$\sigma_2(t_{2r-past}) = \langle\langle$be-abandoned, $x_{vincent}$, x's crew, $t_{2r-past}$; $1\rangle\rangle$

$\sigma_3(t_{3r-past}) = \langle\langle$sink, $x_{vincent}$, $t_{3r-past}$; $1\rangle\rangle$

Then, given a dynamic situation s in which the temporal ordering: $t_1 < t_2 < t_3$ holds and a time interval t, say yesterday, with its subintervals t_1, t_2, and t_3, we can obtain the following propositions:

(76) $s \models (\sigma_1(t_{1r-past}) \wedge \sigma_2(t_{2r-past}) \wedge \sigma_3(t_{3r-past}))$

(77) $s \models \sigma_1(t)$, $s \models \sigma_2(t)$, and $s \models \sigma_3(t)$,

where

$\sigma_1(t_{1r-past}) = \langle\langle$be-hit, $x_{vincent}$, $y_{harpoon}$, $t_{1r-past}$; $1\rangle\rangle$

$\sigma_2(t_{2r-past}) = \langle\langle$be-abandoned, $x_{vincent}$, x's crew, $t_{2r-past}$; $1\rangle\rangle$

$\sigma_3(t_{3r-past}) = \langle\langle$sink, $x_{vincent}$, $t_{3r-past}$; $1\rangle\rangle$

and

$\sigma_1(t) = \langle\langle$be-hit, $x_{vincent}$, $y_{harpoon}$, t; $1\rangle\rangle$

$\sigma_2(t) = \langle\langle$be-abandoned, $x_{vincent}$, x's crew, t; $1\rangle\rangle$

$\sigma_3(t) = \langle\langle$sink, $x_{vincent}$, t; $1\rangle\rangle$

This proposition claims that a series of temporally sequential events occur in the situation s. But it also claims that those events are understood as occurring in the same interval of time t, say yesterday.

3. Concluding Remarks

The purpose of this paper was to show that an indexical approach based on Reichenbach's notions of speech, event, and reference times would be a particular application of Situation Theory to the semantics of tense in natural language. For this purpose, I have first shown how the notions of described, discourse, background or resource situations can be effectively used to develop an adequate semantics for tensed statements in English. I have then adopted an equation solving approach to develop a compositional treatment of representing meaning or information structures involving tense. Lastly I have finally devised some ways of differentiating described or discourse situations to formulate constraints on discourses and to induce dynamic interpretation from tensed statements or discourses.

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