TEMPORAL RELATIONS IN TEXTS AND TIME LOGICAL INFERENCES

Jürgen Kunze

Central Institute of Linguistics

Academy of Sciences of GDR

DDR-1100 Berlin

Abstract: A calculus is presented which allows an efficient treatment of the following components: Tenses, temporal conjunctions, temporal adverbials (of "definite" type), temporal quantifications and phases. The phases are a means for structuring the set of time-points t where a certain proposition is valid. For one proposition there may exist several "phase"-perspectives. The calculus has integrative properties, i. e. all five components are represented by the same formal means. This renders possible a rather easy combination of all informations and conditions coming from the aforesaid components.

1. Prerequisits

We assume that propositions are replaced by phase-sets: A proposition R is something which is true or false at each point t of the time axis U:

Value(R,t) = T(rue) or F(alse).

A phase is an interval (span or moment) p on the time axis, which a truth value (denoted by q(p)) is assigned to:

q(p) = T: p is an affirmative (main-)phase.

q(p) = F: p is a declining (secondary) phase.

A phase-set P is a pair [P*,q]: P* is a set of intervals p and q is an evaluation function assigning a truth value to each $p \in P^*$.

The substitution of propositions R by phase-sets P is not unequivocal, but also not arbitrary. Some necessary conditions for the relationship between R and its "surrogate" P have been introduced and discussed elsewhere (Kunze 1986). One essential point is that the simple "moment logic" becomes an "interval logic".

This is also connected with questions as expressed by the different definitions of HOLD, OCCUR and OCCURING in Allen 1984.

Another fact connected with phases is the unsymmetry in the case of a negation:

(1) The museum is open today.

$\neq$ The museum is open all day today.

(2) The museum is closed today.

= The museum is closed all day today.

The proposition R is supposed to be fixed and given. P is considered as variable and provides a formal counterpart of different phase-perspectives for a certain proposition. The German sentence

(3) Thomas raucht.

has at least two of them (and consequently two meanings): "Thomas is a smoker" and "Thomas is smoking". Furthermore the use of phases enables us to consider some parts of T(R) as unimportant, accidental or exceptional. These parts form declining phases of R. The affirmative phases of R need not be disjunct, and they need not be contained in T(R). It is also possible to introduce nested phases, so that rather complicated courses may be represented.

2. Some formal definitions

Let $P_i = [P_i^*, q_i]$ (i = 1,2) be two phase-sets with $P_1^* = P_2^*$. Then P_1 and P_2 may be connected by means of sentential logic: For any functor "o" (e. g. "... and ..." and, "if ..., then ..."), one defines

$P_1 \circ P_2 \overset{=}{\text{Def}} [P^*, q_1 \circ q_2]$ with $P^* = P_1^* = P_2^*$.

Phase-operators connect arbitrary phase-sets. As an example we take the phase-operator OCC:

$[P^*,q] = P = OCC(P_1,P_2)$ means $P^* = P_1$ and

$$q(p) = \begin{cases} T, & \text{if } q_1(p) = T \text{ and there is a } p_2 \in P_2 \\ & \text{with } q_2(p_2) = T \text{ and } p \cap p_2 \neq \emptyset, \\ F & \text{otherwise.} \end{cases}$$

If one replaces " $p \cap p_2 \neq \emptyset$ " by " $p \subseteq p_2$ ", one gets the definition of $P = PER(P_1,P_2)$.

$P = OCC(P_1,P_2)$ means "P_2 happens during P_1",

$P = PER(P_1,P_2)$ "P_2 happens throughout P_1".

The important point is that these relationships between P_1 and P_2 are not represented by a Yes-No-decision, but again by a phase-set P: $OCC(P_1,P_2)$ selects from the T-phases of the first argument those p for which the characteristic condition (= there is a p_2

with $q_2(p_2)$ = T and $p \cap p_2 \neq \emptyset$) is fulfilled.

The phase-operator OCC is not the same thing as OCCUR or OCCURING in Allen 1984. There are at least three differences: OCCUR is a Yes-No-predicate, has as first argument an event and as second an interval, and the arguments are no sets as in our case. It makes at any rate difficulties to generalize such a Yes-No-property for sets as arguments. This is one reason for our definitions. More important is that e. g. $OCC(P_1,P_2)$ may be used as argument in another phase-operator. This enables us to express quite easily the essential time relation in "In July there are evening-planes on Tuesday and Friday.".

One needs some other operations: Given P = [P*,q], then alt(P) contains exactly those phases which one gets by joining all phases of P which are not seperated from each other and have the same q-value (inductively understood).

If one designates by U^o the phase-set consisting only of U as interval (with q(U) = T), then alt(P) = U^o means that the union of all T-phases of P covers the time axis U, i. e. "P is always true".

In sect. 1. we already sketched how to represent propositions R by phase-sets P. We write P = <R>. Now we have to explain the same for temporal adverbials: <tuesday> is a phase-set P, whose intervals p are the days, and exactly the Tuesdays have the q-value T. In <day> all intervals (= day) have the q-value T. <1982> is a phase-set with years as intervals, but only one (="1982") has the q-value T. Obviously x<tuesday> is a single unspecified Tuesday, x<day> an unspecified day.

3. Examples

Now we are ready to give some examples. Let be R = "John goes to see Mary". <R> = P is obviously the set of all visits of John to Mary. Then we have:

(4) In 1982 John want to see Mary every Tuesday.

is represented by the following condition ("→" for "if ..., then ..."):

(5) alt(<1982> → PER(<year>, ...
alt(<tuesday> → OCC(<day>,P)))) = U^o

This has to be read as: It is true (alt(...) = U^o), that 1982 is a year, during which (<1982> → PER(<year>, ...) it was/is/will be always the case (alt(...)) that every Tuesday is a day, when it occurred/occurs/will occur (<tuesday> → OCC(<day>, ...)) that R happens. It should be noted that (5) has no reference to tenses! Whereas (4) represents something with the logical status of being true or false, (6) defines a certain phase-set:

(6) The Tuesdays when John want to see Mary

The corresponding expression is

(7) OCC(<tuesday>,P).

This time the additional condition is not alt(...) = U^o as before, but alt(...) $\neq \sim U^o$ ("~" as sign for negation, $\sim U^o$ the phase-set containing only U as interval with q(U) = F):

(8) alt(OCC(<tuesday>,P) = $\sim U^o$

This means:

(9) There is at least one Tuesday when R happened.

In this case it is possible to apply the x-operation (to (7)):

(10) xOCC(<tuesday>,P)

This can be paraphrased as

(11) A Tuesday when John went to see Mary

Behind these examples stand some general questions: The two condition alt(...) = U^o and alt(...) $\neq \sim U^o$ have the status of truth-conditions. They refer to the two cases, where a phase-set is considered as a Yes-No-property and where it is the basis for a determined (or defined) time, which is again a phase-set. This becomes clear by

(12) As long as John went to see Mary every Tuesday (she believed in his promise of marriage).

These spans (there may be more!) have to be represented by

(13) alt(<tuesday> → OCC(<day>,P))

with truth-condition alt(...) $\neq \sim U^o$ (for (12) becomes inacceptable, if there is no such Tuesday at all!). Is $\overline{R}$ = "Mary believes in John's promise of marriage" and <$\overline{R}$> = $\overline{P}$, so

(14) $\text{alt}(\text{PER}(\text{alt}(\langle\text{tuesday}\rangle \rightarrow \text{OCC}(\langle\text{day}\rangle,P)),\overline{P})) = U^{o}$

is the corresponding expression for (12). If we take (13) as $\tilde{P}$, (5) becomes

(15) $\text{alt}(\langle 1982\rangle \rightarrow \text{PER}(\langle\text{year}\rangle,\tilde{P})) = U^{o}$

and (14) becomes

(16) $\text{alt}(\text{PER}(\tilde{P},\overline{P})) = U^{o}$.

Using the definition of PER one gets

(17) $\text{alt}(\langle 1982\rangle \rightarrow \text{PER}(\langle\text{year}\rangle,\overline{P})) = U^{o}$,

which can be paraphrased as

(18) During 1982 Mary believed in John's promise of marriage.

This answers a second general question: Time logical inferences may be based on these expressions which represent phase-sets.

Another question concerns quantification. The expressions avoid the (always troublesome) quantification and render it possible to perform the inferences rather simply. The quantifications are "hidden" in the following sense: The expression

(19) $\forall x \exists y \ \text{alt}(\text{OCC}(xP_1,yP_2)) \neq \sim U^{o}$

(for every T-phase p_1 of P_1 there is a T-phase p_2 of P_2 such that p_2 happens during p_1) is equivalent to

(20) $\text{alt}(P_1 \longleftrightarrow \text{OCC}(P_1,P_2)) = U^{o}$

(an expression without formal quantification!). It can be proved, that for every expression with (linguistically reasonable) quantification there is an equivalent expression without explicit quantification.

The expressions reflect in fact a structure of texts. The constituents of this structure belong to two categories: "propositional" and "temporal", where the second includes some quantifications (<u>every</u> Tuesday, <u>only</u> on Tuesdays), frequencies (three times), measures (for <u>three days</u>), (21) gives a simplified version of this structure for (12):

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(21) As long as               t.......┐
     John want to see Mary    p..┐    } t..┐
     every Tuesday            t..} p..┘    } p
     she believed ...         p............┘
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So we have three types of structures (if we restrict ourselves to the sentence-level):

(a) the syntactic structure (e.g. a dependency tree),

(b) the macrostructure as in (21), which has some features of a constituent tree, but reminds more of categorial grammar, if one considers the problem thoroughly,

(c) the structure of the expression (14) for (12).

They may be used as interface structures for two steps of analysis. The step from (b) to (c) has to apply rules, which we already used for (5):

(22) P every Tuesday $\Rightarrow$ $\text{alt}(\langle\text{tuesday}\rangle \rightarrow \text{OCC}(\langle\text{day}\rangle,P))$

(23) as long as P , P $\Rightarrow$ $\text{alt}(\text{PER}(P,\overline{P}))$

etc. It should be noted, that the three essential temporal parts in (21) are expressed by totally different means:

Tuesday : phase-set
every : ... → PO(...,...)
(PO = variable phase-operator)
as long as : phase-operator

Another example is

(24) P only on Tuesdays $\Rightarrow$ $\text{alt}(\text{OCC}(\langle\text{day}\rangle,P) \rightarrow \langle\text{tuesday}\rangle)$

<u>References</u>:

James F. Allen, Towards a General Theory of Action and Time; Artificial Intelligence 23 (1984), p. 123 - 154

Jürgen Kunze, Probleme der Selektion und Semantik, to appear 1986 in Studia Grammatica, Berlin