Four Types of Temporal Signals

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Abstract

Temporal prepositions in English signal various temporal relations over events and times. In this paper, we propose to categorize such signals into four types: **locative**, **measure**, **boundary**, and **orientation** signals. We show that each of these signal types is constrained by its own semantic restrictions. First, each of them takes as its argument a temporal entity structure either of an *atomic type* such as dates, periods of time, and time lengths or amounts, or of a *complex type* such as bounded intervals ("*from* dawn *till* dusk") and oriented intervals with their lengths specified ("an hour *after* the sunset"). Second, each signal type determines the semantic type, called *aspect*, of an eventuality that it is associated with. Such an analysis of temporal signals, as we claim, lays a basis of developing an integrated spatio-temporal annotation scheme for language, especially involving motions.
Keywords: atomic type, complex type, entity structure, eventuality, interval, locative, oreinted span, time amount, time length

1 Introduction

There is only a small set[1] of prepositions in English that function as spatial and temporal signals. Prepositions such as *at, in, during, by, since, from, to, through, till, before*, and *after* in English trigger various temporal relations over events, times or locations.

ISO-TimeML (2012) puts these prepositions used as temporal signals under one single type **signal**, tagged <SIGNAL>. In this paper, we propose to categorize this one signal type into four types of temporal signals, each of which is tagged with the same element name `<signal>`, but is typed differently: **locative signal** `<signal type="locative">`,[2] **measure signal** `<signal type="measure">`, **boundary signal** `<signal type="boundary">`, and **orientation signal** `<signal type= "orientation">`.

Each of these temporal signal types is represented as an *element* in XML, following ISOspace (2014) that represents the two types of spatial signals as *elements* `<spatialSignal>` and `<motionSignal>`. Such a representation makes temporal signals structurally more comparable to spatial signals.

These signals are illustrated by example 1:

(1) Kim stayed in Europe during$_{loSignal}$ the fall of 2010$_{timePeriod}$, visiting various cities in Europe for$_{meSignal}$ three months$_{timeLength}$ from$_{boSignal}$ September$_{calMonth}$ through$_{boSignal}$ November$_{calMonth}$. She had left Seoul a week$_{timeLength}$ after$_{orSignal}$ her graduation.

Each of the four types of signals is illustrated in (1) as being associated with a temporal entity structure of some type. The preposition *during* as a locative signal in (1, line 1) anchors the event of Kim's staying in Europe to the fall of 2010, a period of time. As is illustrated by (1), locative signals such as *during* trigger the anchoring of an event to an extended interval of time, while locative signals such as *at* and *on* anchor an event to a minimal interval of time, often called *instants*. This difference comes from differences in the aspectual semantic features of eventualities.

[1] Bennett (1975) lists 38 prepositions one of which he claims is a dialectal variation.
[2] The term *locative* here is used in a temporal sense.

The signal *for* as a measure signal that occurs in (1, line 3) associates that eventuality with the temporal expression *three months* that denotes a length of time. The signals *from* and *through* as a pair in (1, lines 4 and 5) mark a bounded interval (duration) with its boundaries, start and end, of Kim's stay in Europe or traveling around there. The signal *after* in (1, line 7) places Kim's departure from Seoul some time later than her graduation with a forward orientation, but with the length of an intervening interval specified between her graduation and departure as being a week. That time of Kim's departure is thus identified with the endpoint of that interval.

The ultimate purpose of this paper is to provide a basis for designing an integrated spatio-temporal annotation scheme on an enriched system of temporal signals which are interoperable with spatial signals. This paper, however, focuses solely on the classification of temporal signals which depends on how each of the signals is related to a different type of temporal entity structures.

The rest of the paper is organized into four sections. In section 2, we restructure temporal entity structures into two types: *atomic* and *complex*. In section 3, we relate four types of temporal signals to these two types of temporal structures. We finally show in section 4 how these signals interact with various semantic types of eventualities that they modify.[3] Section 5 concludes the paper with a summary.

2 Re-structuring Temporal Entity Structures

2.1 Overview

Both TimeML and ISO-TimeML (2012)[4] put every type of temporal expressions referring to times, dates, durations, measures, frequencies, and quantified times under one category, tagged <TIMEX3>. However, following Hobbs and Pan (2004), Bunt (2011) classifies them into three types: *instants* that refer to temporal points, time *intervals*, and then *time amounts*. Frequencies and quantified temporal entities also form different classes, but are treated in a different domain.

We propose to classify all of the temporal entity structures, except for frequencies and quantifications,[5] by generalizing entity structures into two types, *atomic* and *complex*. We then treat temporal entity structures as particular cases of those sub-typed entity structures.

2.2 Atomic vs Complex Entity Structures

Bunt (2007) and his subsequent works (Bunt, 2010, 2011) introduce the notion of *entity structures* as a pair $<m, A>$, where m is a markable in text and A a list of annotations on m. Lee (2012) then proposes to categorize entity structures into two types: *atomic* and *complex*, for there are some entity structures, as to be treated of the complex type, which refer to two or more entity structures like link structures.

Some entity structures such as spatial or temporal locations (e.g., *Seoul, the city, December 2016, the morning*)[6] are annotated by themselves without making any reference to other entity structures. In contrast, entity structures like paths or durations (e.g., *California Highway 1 from San Francisco to Carmel* or *half a day from noon to midnight*) are annotated with reference to other spatial or temporal entities.

This distinction can be stated, as follows:

(2) **Complex Entity Structure**
Given a markable m and a list A of annotations on m, an entity structure $<m, A>$ is called *complex* if and only if any of the components in A refers to another entity structure; otherwise, it is *atomic*.

[3]The term *eventuality* was coined by Bach (1986) as a cover term that comprises all of the aspectual types of states or events or other Vendler classes.

[4]TimeML is briefly introduced in Pustejovsky et al. (2005) and ISO-TimeML in Pusejovsky et al. (2010) and Pustejovsky (2017a).

[5]These two types have been discussed by Pratt-Hartmann (2005), Bunt and Pustejovsky (2010) and Lee and Bunt (2012) withtin the framework of TimeML or ISO-TimeML.

[6]In this paper, we often talk about entities without differentiating them from their annotated structures.

We apply the notion of *atomic* vs *complex* entity structure, as stated above, directly to a way of differentiating temporal entity structures into two types, *atomic* and *complex*, as to be discussed in 2.3 and 2.4, respectively.

Exceptions to the definition of complex entity structure as given in (2) are three kinds: (1) indexical expressions (e.g., *today, last year*), (2) pronominal or anaphoric expressions (e.g., *they, she, that time*), and (3) markables as targets in semantic annotations. Indexical expressions refer to discourse entities introduced in a discourse situation or model, anaphoric expressions to their antecedents, and markables to morpho-syntactic annotations. Entity structures referred to by these expressions are not treated as of the complex type, although they refer to other entity structures or entities.

2.3 Atomic Temporal Structures

There are two sorts of atomic temporal structures: *simple intervals* and *temporal measures*.[7]

2.3.1 Simple Intervals

Simple temporal intervals are either minimal (instances) or extended (periods). They include dates, times of day (e.g., morning, noon, afternoon, evening, night), clock times (hour, minute, second), and periods of time (season, year, decade, century, millennium). They all can be viewed as either minimal intervals (instances) or extended intervals (periods), depending on what type of eventualities they modify. These entities are directly referenced to by temporal expressions such as dates, clocktimes or periods of time, without referring to other temporal entities.

Here are examples in (3):

(3) a. Mia got up$_{e1}$ at seven$_{t1}$ in the morning$_{t2}$.

b. Mia stayed home during the summer$_{t3}$ of 2016$_{t4}$.

The clocktime $seven_{t1}$ refers to the seventh hour of a day. The time expression $the\,morning_{t2}$ refers to the first half period of a day. Both $summer_{t3}$ and *2016*$_{t4}$ refer to periods of time, a season and a year, respectively. All of them refer to definite times without referring to other times. They are thus treated as referring to temporal entity structures of the *atomic* type.

2.3.2 Temporal Measure: Length vs Amount

There are two closely related notions of time measure: *time length* and *time amount*. They refer to different dimensions of measure. In general, a length is a property of an interval, either spatial or temporal, which constitutes either a path or a duration. A length is quantitatively measured in terms of a real number and a unit, which is either spatial or temporal: e.g., *15 meters* vs *15 minutes*. We thus define the notion of *temporal length*, as in:

(4) **Time Length**
$length$ is a function $l:\ I \to R \times U$,
where I is a set of time intervals, R a set of reals and U a set of temporal units.

There is another term *time amount*. We use it in a technical sense to refer to a time measure, sometimes called *runtime*, which is the time consumed by an eventuality. The *time amount* is thus defined, as in:

(5) **Time Amount**
A *time amount* is a function $\tau:\ E \to R \times U$,
where E is a set of eventualities, R a set of reals, and U a set of temporal units.

According to these definitions, as given in (4) and (5), both a length of time l and an amount of time τ may have the same measure of values, such as $<10, hour>$ (*ten hours*), but their domains are different. Formally speaking, the domain of length l is a set of time intervals I, whereas that of amount τ is a set of eventualities E.

[7] Frequencies and quantified times are also of the atomic type.

2.4 Complex Temporal Structures

Temporal entity structures of the *complex* type, in contrast, are characterized in their reference to other temporal entity structures. These entity structures may be either (1) bounded intervals (durations) or (2) oriented intervals (directed spans).

2.4.1 Bounded Intervals (Durations)

Bounded intervals, more often called *durations*, have their boundaries, start or end, or both, specified by boundary signals (`<signal type="boundary">`) such as *from* and *till* as a pair. These intervals are temporal entity structures of the complex type, for they refer to their boundary points (minimal intervals), being represented as a triplet below:

(6) A bounded interval t, delimited either partially or totally by its specifically mentioned boundaries, t_i and t_j: $<t, t_i, t_j>$, or $\lambda t[starts(t_i, t) \wedge ends(t_j, t)]$.

Here are examples:

(7) a. Mia slept$_{e1}$ $\emptyset_{t3}$ *from* ten$_{t1}$ *till* seven$_{t2}$.

b. Mia will get$_{e2}$ better $\emptyset_{t5}$ *from* now$_{t4}$ on.

Example (7a) above contains the two time expressions, ten_{t1} and $seven_{t2}$, each referring to a clock time, an atomic entity structure type. Because of the temporal signals, these times, however, refer to the two boundaries, *start* and *end*, of an interval which is marked up as a non-consuming empty tag, $\emptyset_{t3}$.[8] Hence, this interval $\emptyset_{t3}$ forms an entity structure of the *complex* type, delimited by its two boundaries, t_1 and t_2.

Likewise, example (7b) also marks up an interval $\emptyset_{t5}$ with its start boundary t_4 explicitly mentioned and referred to by *from now*, while its end boundary is not mentioned and left open. This semi-open interval is also a temporal entity structure of the complex type with a temporal signal *from* that is triggering a temporal entity *now* to be its start boundary.

2.4.2 Oriented Intervals

There are temporal intervals which are oriented either forward or backward,[9] as triggered by signals such as *after, before*, and *ago*[10].

Here is an example:

(8) Mia left$_{e1}$ for Busan two hours$_{t6}$ after$_{s1}$ her breakfast$_{e2}$.

Determining the orientation type and the anchoring ground depends on the type of signals as well as the semantic type of eventualities. The signal *after* triggers a forward oriented interval t at the end t_j of which the event e_1 of Mia's leaving is anchored, as shown by Figure 1. The semantic type of Mia's leaving is a transition (accomplishment) type.

[8] In parsing or semantic annotation, an element (in XML) which has no reference to a textual fragment is called a *non-consuming tag*. For example, in a gapping structure such as *Bill loves apples and Ben $\emptyset$ pears*, a verb is missing in the right conjunct. This missing verb, marked by $\emptyset$, is treated as a non-consuming tag. The tag is there, but it is not *consumed by* nor refers to any markable expression in text.

[9] Quirk et al. (1985) (section 8.5) use the *forward* or *backward span* to explain phenomena that are related to these orientation signals.

[10] Unlike other temporal triggers that are mostly prepositions, *ago* is an adverbial trigger.

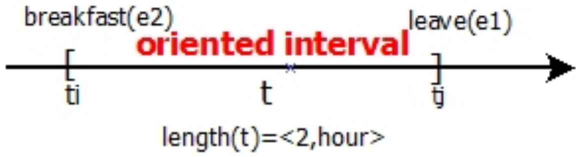

Figure 1: Forward Oriented Interval

3 Four Types of Temporal Signals Revisted

3.1 Overview

Temporal signals are classified into four types, depending on the type of a temporal entity structure which each of them is associated with, as shown in:

(9) a. Associated with Atomic Temporal Entity Structures:
(1) Locative signals `<signal type="locative">` for times proper;
(2) Measure signals `<signal type="measure">` for temporal measure.

b. Associated with Complex Temporal Entity Structures:
(3) Boundary signals `<signal type="boundary">` for bounded intervals;
(4) Orientation signals `<signal type="orientation">` for oriented intervals with their lengths specified.

3.2 Locative Signals

Locative signals such as *at, in, on, during*, and *by* are used in both temporal and spatial senses. These signals all refer to temporal locations, also called *time-positions* by Quirk et al. (1985).[11] Unlike the prepositions such as *at, in*, and *on*, the preposition *during* is used in a temporal sense only. The preposition *by* is used in both spatial and temporal senses, but these two senses are not related.

The locative signals *at* and *in* in examples (10) each anchor an eventuality to an atomic-type time.

(10) a. Mia arrived$_{e1}$ at$_{loS1}$ nine-fifteen$_{t1:clocktime}$.
$[arrive(e_1) \wedge past(e_1) \wedge occurs(e_1, t) \wedge t = t_1 \wedge hour(t_1) \wedge clocktime(\text{KST}, t_1) = 9:15]$[12]

b. Mozart lived$_{e_2}$ in_{loS_2} [the eighteenth century]$_{t_2:period\,of\,time}$.
$[live(e_2) \wedge past(e_2) \wedge holds(e_2, t) \wedge t \subset t_2 \wedge century(t_2) \wedge period(\text{CE}, t_2) = 18]$[13]

The time-related event predicates **occurs** and **holds**[14] are accompanied by their respective constraints. The predicate **occurs** is constrained by an equality relation $=$ between an event time t and a mentioned or referenced time t_1 as in (a), whereas the predicate **holds** is constrained by an inclusion relation, represented by a subset relation $\subset$, between the two times, t and t_2. The length of the time t in the interval t_2 is, however, determined by a pragmatic factor. It is a historical fact that Mozart did not live throughout the whole period of the eighteenth century, but for only a portion of it.

3.3 Measure Signals

Measure signals such as *for* and *in* take temporal measure entities, time lengths or time amounts, as their arguments. Here is an example:

[11] See Quirk et al. (1985), 8.51 Adjuncts of time.
[12] KST stands for the Korean Standard Time, which is GMT + 9 hours.
[13] CE stands for the Current or Christian Era, replacing AD, *Anno Domini*.
[14] We follow the interval temporal logic of Allen (1984) and Allen and Ferguson (1994) and their definition of these predicates.

(11) I taught at a university ($for_{meSignal}$) *almost 40 years*$_{tMeasure}$, but have to retire $in_{meSignal}$ *a year*$_{tMeasure}$.

As shown in the example, the signal *for* may be omitted, but the signal *in* may not.

The temporal entities referred by these measure expressions, however, are of two different types. The time measure associated with the signal *for* is an amount time that is consumed by an eventuality, involving an extended time interval, called *time span*. This amount can be a cumulative quantity. The signal *in*, in contrast, is simply associated with a length of a time interval at the end of which an associated event comes to a culmination point, thus being called *time frame*. Differences in their use have been discussed by Vendler (1967), Kenny (1963), Mourelatos (1978), Croft (2012), and many others in relation to the semantic aspectual types, especially *achievement* and *accomplishment* types, of eventualities that those measure signals are used with. In section 4.3, we resume this topic discussing the use of temporal measure signals related to such eventuality types.

3.4 Boundary Signals

Intervals are often bounded by their boundaries, represented by the predicates **starts** and **ends**. Here are examples:

(12) a. Mia visited Thailand *from* **January 5** *to* **20** this year.

b. Some workmen have to work *from* **dusk** *till* **dawn**.

Bounded intervals may occur with specific measure expressions:

(13) a. Mia slept **the whole morning** *from early morning till noon*.

b. Kim has been sick *for* **six straight days** *from Monday through Saturday*.

The measure expressions supplement the meaning of their respective bounding intervals.

3.5 Orientation Signals

As Quirk et al. (1985) suggest, the main function of orientation signals is to locate event times either forward (future oriented) or backward (past oriented) with respect to their reference times. Here is a short list:

(14) a. Forward: *after, since, from*
b. Backward: *before, ago*

These signals may occur with or without any oriented intervals. Here are examples:

(15) a. Gio left for Paris *two weeks*$_{orInterval}$ after$_{orSignal}$ Easter$_{rTime}$. [forward]

b. Gio will return home *a week*$_{orInterval}$ before$_{orSignal}$ Christmas$_{rTime}$. [backward].

The forward orientation signal places each oriented time interval at a later position with respect to the reference time,[15] whereas the backward orientation places that interval at a position earlier than the reference time. The event time is grounded to one of the boundary points, depending on the directionality of the signal: if a given interval is forward oriented as in (15a), then the anchoring ground point is the end of that interval, whereas the anchoring ground is its start point if the interval is backward oriented.

There is, however, an ambiguity in interpreting these so-called oriented intervals especially when such an interval modifies *state*-type or *process*-type eventualities. Consider:

(16) a. Mia has lived in Seoul *12 years*$_{orInterval}$ since$_{orSignal}$ 2005$_{rTime}$.

b. Mia has lived in Seoul *for 12 years*$_{orInterval}$ since$_{orSignal}$ 2005$_{rTime}$. [state]

c. Jon has been smoking *(for) six years* after$_{orSignal}$ his military service. [process]

Sentence (16a) is acceptable only if it is interpreted as (16b). In this case, the eventuality of Mia's having lived in Seoul is anchored to the whole interval. The same type of interpretation applies to (16c).

[15] See Reichenbach (1947) for the notion of reference time in contrast to that of event time.

4 Types of Eventualities Interacting with Temporal Structures

The interpretation of temporal structures, consisting of time signals and entities, which syntactically function as temporal adjuncts, is much restricted by the type of an eventuality which they occur with. In this section, we discuss how they interact with each other.

4.1 Basic Assumptions

We assume an ontology of eventualities that amalgamates Allen (1984) and Pustejovsky (1991), which is then modified by Pustejovsky et al. (2017) (page 32, (10)) that subcategorize the type of *transition* into *achievement* and *accomplish* types, as in Vendler (1967).[16]:

(17) `eventuality types = state (property) | occurrence;`
`state (property) =` e`;`
`(*`e `stands for a single homogeneous eventuality.*)`
`occurrence = process (activity) | transition;`
`process (activity) =` $e_1 ... e_n$`; (* where` $n \geq 2$ `*);`
`(*A process is defined to be a sequence of more than one eventualities that may not be homogeneous.*)`
`transition = transition`$_{ach}$ `| transition`$_{acc}$`;`
`transition`$_{ach}$ `=` $e_1 e_2$`; (*where` e_1 `and` e_2 `are states.*);`
`transition`$_{acc}$ `=` $e_1 ... e_n e_c$`;`
`(* The sequence` $e_1 ... e_n$ `is a process and` e_c`, a culminating state.*)`

The notion of *achievement* here is understood as consisting of a state followed by another state, but we extend it to include a case in which a state is followed by a process as the inverse of an accomplishment. This is represented as below:

(18) Extended Notion of Achievement:
`transition`$_{ach^e}$ `=` e_i $e_1 ... e_n$`;`
`(*where` e_i `is an initial state and` $n \geq 1$`.*);`

We also assume, as stated earlier in section 3.2, the interval temporal logic of Allen (1984) and Allen and Ferguson (1994) with their definitions of two predicates **holds** and **occurs**. A *state* or *property* is a static eventuality that *holds* over an interval of time and every subinterval of it. An *occurrence* is of a dynamic type that consists of a sequence of sub-events which may not be uniform nor contiguous as it develops. There are two subtypes of *transition*: $transition_{ach}$ for achievements and $transition_{acc}$ for accomplishments.[17] *John woke up at seven* is an example of achievements in which a state of John's being asleep changes to the state of his being awake. The activity of *John wrote a novel* involves a process of writing and then reaches the culminating state of finishing a novel. This is an example of accomplishments.

We then understand that an *instance* is a minimal interval, thus treating the two boundary points of a time interval as two minimal intervals, called *start* and *end*. The predicates corresponding to them are **starts** and **ends**, each representing a relation between an interval and its begin-point and endpoint, respectively.

4.2 Locative Constructions

Locative constructions represent simple intervals, each triggered by locative signals. Consider:

(19) a. John woke up at seven thirty-five$_{clocktime}$. [transition$_{ach}$]

b. Mozart lived$_{t_e}$ in the eighteenth century$_{t_r}$. [state]

[16] We represent the structure of eventuality types in extended BNF (ISO/IEC 14977, 1996)
[17] See Pustejovsky et al. (2017) page 32, (10).

The interpretation of (19a) is represented by the predicate **occurs** because the verb *woke up* is of a transition type. That of (19b), in contrast, is represented by the predicate **holds** because the verb *lived* is of a state type. Note, however, that there is a subinterval constraint between an event time t_e and a reference time t_r which affects the interpretation **holds** relation.

4.3 Measure Constructions

The *for*-measure expression provides an answer to a *how long*-type question, whereas the *in*-measure expression provides an answer to a *when*-type question as well as *how long*-type question with *it takes*, as illustrated by (20).

(20) a. *How long* did you teach at a university?
(For) almost forty years.

b. *When* will you retire?
In a year.

c. *How long* did it take for Mia to write a book?
It took almost six months. In fact, she wrote it in exactly five months and three weeks.

The semantic content of the *for*-measure expressions can be represented as shown by (21):

(21) a. We worked$_{e1}$ for$_{meS1}$ 10 hours$_{me1}$.
$[work(e_1) \wedge past(e_1) \wedge occurs(e_1, t) \wedge \tau(e_1) = <10, hour>]$[process]

b. John waited$_{e2}$ for$_{meS2}$ more than 2 days$_{me2}$ to get a visa.
$[wait(e_2) \wedge past(e_2) \wedge occurs(e_2, t) \wedge t \subset t_2 \wedge l(t_2) \geq <2,\text{day}>]$ [process]

The *for*-measure expressions are associated with *process*-type eventualities. Their temporal properties are represented by the time amount τ that each process has taken. The time amount of the occurrence $worked_{e1}$ was $10\, hours_{me1}$, which might have been measured cumulatively. The length l of the time interval in which the event of $waited_{e2}$ lasted was a stretch of *more than 2 days*$_{me2}$.

The semantic content of the *in*-measure expressions can be represented as illustrated by (22):

(22) a. Mia wrote$_{e1}$ a book in_{meS1} six months$_{me1}$.
$[write(e_1) \wedge past(e_1) \wedge occurs(e_1, t) \wedge t \subseteq t_1 \wedge ends(t, t_1) \wedge l(t_1) = <6, month>]$ [transition$_{acc}$].

b. I will retire$_{e2}$ in$_{meS2}$ a month$_{me2}$.
$[retire(e_2) \wedge future(e_2) \wedge occurs(e_2, t) \wedge ends(t, t_2) \wedge l(t_2) = <1, month>]$ [transition$_{ach}$]

Unlike the signal *for*, which is associated with *process*-type eventualities, the signal *in* is, in contrast, associated with *transition*-type eventualities. The time t is the culmination point of an interval t_1 or t_2, as represented with the predicate **ends**. These two, however, differ from each other: (22a) is an accomplishment involving a process, represented as $t \subset t_1$, through which the activity of writing a book holds, whereas (22b) is an achievement which just occurs at the end of the given time interval.

The signal *for* can also be used with *state*-type eventualities, as illustrated by (23):[18]

(23) a. James Pustejovsky *was CTO* for five years.
$[be\text{-}CTO(e_1) \wedge past(e_2) \wedge holds(e_1, t) \wedge t \subseteq t_1 \wedge l(t_1) = <5, year>]$ [state]

b. They *lived* in U.N.-run refuge camps for two and a half years.
$[live(e_2) \wedge past(e_2) \wedge holds(e_2, t) \wedge t \subseteq t_2 \wedge l(t_2) = <2.5, year>]$ [state]

These two states lasted throughout the entire time intervals (durations) as mentioned.

[18]These examples are taken from ISO-TimeML (2012), A.2.1.3.3 (35).

4.4 Bounded Intervals

Eventualities of the type *process* or *state* occur during a bounded interval. Accomplishment types are also allowed during a bounded interval, while achievements are not.

(24) a. My mother has been ill since last year. [state]

b. My girl friend worked there till Christmas. [process]

c. I have been writing a novel from the spring of last year till this autumn. [transition$_{acc}$]

d. *My girl friend arrived there till Christmas.[19][transition$_{ach}$]

These examples show that bounded intervals occur with *state, process* or *accomplishment*-type eventualities only. The *accomplishment* type occurs in a bounded interval because it involves a process, unlike the *achievement* type.

4.5 Orientation Intervals

Oriented intervals, triggered by orientation signals, can easily occur with *achievement*-type eventualities. Here are examples for the *achievement* type:

(25) a. Mia left for France a month before Easter. [transition$_{ach}$]

b. We will meet a week from today. [transition$_{ach}$]

c. Jon died an hour before midnight. [transition$_{ach}$]

d. I submitted a paper an hour before the deadline. [transition$_{ach}$]

In the case of an *achievement*-type eventuality as in the above example, its anchoring ground is a boundary point of a given oriented interval.

States and processes are allowed if the oriented intervals are interpreted as so-called time spans like the *for*-measure expressions.[20]

(26) a. My family lived in Osaka *(for) almost 15 years* before the end of World War II. [state]

b. My family was living in Osaka *up till almost a year* before the end of World War II. [state]

In these cases, each state is anchored to the whole oriented interval.

(27) a. Mia studied French in Paris *(for) a semester* after her arrival. [process]

b. Mia studied French in Paris *a semester* after her arrival. How she managed to put it off for this long I can't understand.[21] [transition$_{ach^e}$]

Example (27a) is ambiguous: it can either mean that Mia started studying French a semester after her arrival in Paris or that she spent a semester studying it after her arrival. In the case of example (27b), it is clear that Mia started studying French a semester after her arrival, but her study lasted for an indeterminate period of time. The semantic type of the eventuality involved here is considered not a simple achievement ($transition_{ach}$), but an achievement ($transition_{ach^e}$) in an extended sense which defines an achievement as consisting of an initial state followed by either a state or a process, as defined in (18) Extended Notion of Achievement.

[19] Taken from Quirk et al. (1985), 9.37

[20] Gary Rector, a native speaker of English and a professional translator, has noted the ambiguous interpretation of oriented intervals. He also provided some of the examples.

[21] This example was provided by an anonymous native speaker of English, who reviewed a penultimate version of this paper.

5 Concluding Remarks

Table 1 summarizes the whole discussion. There are four types of temporal signals proposed: **locative, measure, boundary**, and **orientation** signals. Some prepositions in English are listed for illustration. Each signal type is associated with a certain type of temporal structure. The first two types mark temporal entity structures of the atomic type such as dates, periods of time, times of day, and an amount or length of time. The other two mark temporal entity structures of the complex type such as intervals with their boundaries specified or oriented spans with time distances, either quantitatively or non-quantitatively specified, or totally unspecified.

Table 1: Summary

signalType	**preposition**	**timeStructure**	**semanticType**
locative	*at, in, on, during*	dates, times, periods	any
measure	*for*	time amounts	state, process
	in	time lengths	transition
boundary	*from – till*, *since*	bounded intervals	state, process, transition$_{acc}$
orientation	*before*, *after*	oriented spans	state^c, process^c, transition$_{ach^e}$

Note: The two *c*-superscripted cases require additional context to allow a durational interpretation.

The last column of Tabel 1 shows what type of eventuality each of the four types of temporal signals is associated with. The locative signals allow an event of any of the semantic types except that *state* or *process*-type events require a more extended interval to anchor them, while *transition*-type events are anchored to minimal intervals, called *instants*. There are at least two types of measure signals, each triggered by *for* and *in*. The trigger for works with *state* or *process*-type eventualities, whereas the trigger in marks *transition*-type occurrences. The bounded interval signal works with *state*, *process* or *accomplishment*-type eventualities. The orientation signals create oriented spans, either forward or backward. States and processes are also interpreted as being anchored to the whole stretch of an oriented interval, but these interpretations are contextually determined. Achievements are each anchored at the boundary point of an oriented interval, but in an extended sense. Each achievement can consist of an initial state followed either by a single state or by a process.

As stated in section 1 Introduction, we have not discussed how our analysis of temporal signals applies to the design of an event-based temporal annotation scheme as a whole. Nor have we shown how these four types of temporal signals correspond to spatial signals. We can, however, point out easily that locative signals correspond to qualitative spatial signals, temporal measure signals to spatial measure signals, bounded temporal intervals to bounded paths, and oriented time distances to oriented spatial distances. Details of these issues are to be discussed on a separate occasion.

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