Four Types of Temporal Signals

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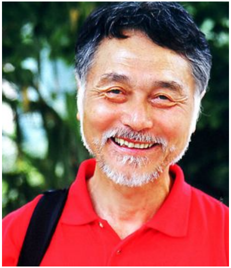

Talk Outline

1. Introduction: Proposal, Claims, and Purpose
2. Modeling Event-related Temporal Structures
3. Atomic vs Complex Temporal Entity Structures
4. Four types of Temporal Signals
5. Concluding remarks

Proposal

- Prepositions in English trigger various temporal relations over events and times.
- In this paper, we propose to categorize such prepositional temporal signals into four types:
  1. Locative signals `<loSignal>` for positional times (dates, periods, and times of the day)
  2. Measure signals `<meSignal>` for time amounts or lengths,
  3. Boundary signals `<boSignal>` for bounded temporal intervals (durations), and
  4. Orientation signals `<orSignal>` for minimal intervals, each delimited with an oriented distance interval (directed span) between an event time and a reference time or event.

Illustrations

(1) a. Kim stayed in Europe during$_{loSignal}$ the fall of 2010$_{timePeriod}$,

b. visiting various cities in Europe for$_{meSignal}$ three months$_{timeMeasure}$

c. from$_{boSignal}$ September$_{calMonth}$ through$_{boSignal}$ November$_{calMonth}$.

d. Kim had left Seoul a week$_{timeLength}$ after$_{orSignal}$ her graduation$_{event}$.

Claims

Each of these signal types is subject to two semantic constraints:

1. Each of the signal types indicates a temporal entity structure either of
   - an atomic type such as dates, periods of time, and time measures, or of
   - a complex type such as bounded intervals ("*from* dawn *till* dusk") and minimal intervals delimited with oriented distances ("an hour *after* the sunset").
2. Each signal type determines the semantic type of an eventuality that it is associated with, such as
   - *state* (*property*) and
   - *occurrence*: *process* and *transition* (*event*)

Source(s): Allen (1984) and Pustejovsky (1991)

Purpose

In this paper,

- we discuss these two semantic features associated with each of the four temporal signal types
- in order to lay a finer-grained theoretical basis for the construction or re-specification of event-related temporal semantic annotation schemes such as
- the semantic annotation framework of ISO 24617-1: 2012, called *ISO-TimeML*, or its possible variants.
- The four-way classification of temporal signals allows a divide-and-conquer approach to a finer-grained specification of temporal annotation.

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Basic Model

Given a language Lg, a model for event-related temporal structures is understood to be a tuple $<E, I, L, R_{type}, \tau, R, U, m, v>$, where E is a non-empty set of eventualities, I, a non-empty set of time intervals, L, a set of links over E, I or from E to I, R_{type}, a set of relation types for each link in L, τ, the *run-time* function from E to I, R, the set of real numbers, U, a set of units, m, the *measure* function from R to U, and v, the valuation function for the interpretation of eventuality, time, and other related expressions in the language Lg.

Event Structures

- `eventuality := state | process | transition`
- *state* (*property*) $:= e$
- *occurrence*:
    - *process* $:= e_1, ..., e_n$
    - *transition* (*event*)

      $\text{transition}_{ach} := \text{state state}$

      $\text{transition}_{acc} := \text{process state}$

Source(s): Vendler (1967), Allen (1984), Pustejovsky (1991), Pustejovsky et al. (2017)

Illustration for Event Structures

1. Mary was sick *for a week*. (state, durative adverbial)
2. Mary walked. (process)
3. Mary walked *for 30 minutes*. (bounded process, durative adverbial)
4. Mary arrived *at noon*. (achievement, point adverbial)
5. Mary walked to the store *in an hour*. (accomplishment, frame adverbial)

Source(s): Pustejovsky(1991)

Interval Time Structures Assumed

- Every temporal entity in *I* can be modeled as an interval, either infinite or finite,
- decomposable into subintervals or minimal intervals, called *points* or *instances*.
- bounded, while an infinite interval is bounded by a minus infinity $-\infty$ and a positive infinity ∞,
- with two particular boundaries, defined by *starts* and *ends*,
- and with a denumerable, possibly null, set of *mid-intervals* between them.

Temporal Relations

- Temporal entities are partially ordered by $\prec$ over I
- with an overlap relation O between two or more intervals, each associated with the holds or occurs relation of an eventuality.
- The decomposition of an interval into subintervals also allows the inclusion relation $\subset$ over intervals.

Relation Types for Each Link

Three Classes of Relations:

1. over eventualities: $L : E \rightarrow E$
2. over time intervals: $L : I \rightarrow I$
3. from eventualities to time intervals: $L : E \rightarrow I$

Relation Types over Eventualities

1. $\sqsubset$, the proper part-of relation over eventualities E,
2. $=$, the identity relation over E.

Relation Types over Time Intervals

1. $\prec$, the precedence relation over time intervals I,
2. O, the overlaps relation over I,
3. $\subset$, the inclusion or subinterval relation over I,
4. *starts*, *ends*, and *meets*, the boundary relations over I,

Relation Types from Eventualities to Time Intervals

1. *holds*, the support relation from E to I, and
2. *occurs*, the anchoring relation from E to I.

Support Relation *holds*

- The predicate *holds* is a relation between a *property* or *state*-type eventuality e and a time interval I: *holds(e,I)*, as defined:
- For any *property* or *state*-type eventuality e and any times I and i,
  $holds(e, I) \Leftrightarrow \forall i[i \subset I \rightarrow holds(e, i)]$
- This definition means that, if any *property* or *state*-type eventuality e holds at a time interval I, then it also holds at every subinterval i of that interval I.

Source(s): Allen (1984)

Examples for the *holds* Relation

Note: `property = state`

1. I rented a car for a month.
2. Mia slept the whole night with just one wakeup. [process?]
3. Mia was busy during the Christmas season.

Anchoring Relation *occurs*

The predicate *occurs* relates an eventuality e of the type *process* or *transition* to a minimal interval (instant) i.

- For any *process* or *transition*-type eventuality e and any time intervals i and i',
  $[[occurs(e, i) \wedge i' \subset i] \rightarrow \neg occurs(e, i')]$
- This means that there is a time interval i at which an eventuality e occurs, but no other time interval within that time interval i at which that eventuality e holds.
- NOTE: Given a process $e = e_1, e_2, ..., e_n$, none of e_i is the same as e, but some e_i can be of the same type of e.

Examples for the *occurs* Relation

Note: `occurrence := process | transition`

1. I played tennis in the afternoon.
   process: non-contiguous with possible breaks
2. I walked from home to school.
   transition: non-uniform sub-events

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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 sub-categorize entity structures into two types:*atomic* and *complex*
- because, unlike atomic entity structures, complex structures refer to other entity structures just like links over entity structures.

Formal Definition

Given a markable *m* and a list of annotations *a* on *m*,

1. an entity structure $<m, a>$ is called *complex* if and only if any of the components in *a* refers to another entity structure;
2. otherwise it is *atomic*.

Atomic Entity Structures

- Some entity structures such as spatial or temporal locations (e.g., *Seoul, the city; December 2016, the morning*) are defined by themselves without making any reference to other entity structures.
- Possible exceptions are: indexical expressions (e.g., *today, last year*), pronominal or anaphoric expressions (e.g., *they, she, that time*) that are linked to their antecedents, and markables as targets in an annotation.
- In contrast, entity structures like paths or durations (e.g., *California Highway 1 from San Francisco to Carmel, half a day from noon to midnight*) are defined with reference to other spatial or temporal entities.

Examples of Atomic Temporal Entity Structures

- Temporal entities of the atomic type include both minimal intervals (instances) and extended intervals (periods of time).
- These entities are directly referenced to by temporal expressions such as dates, clocktimes or periods of time, without referring to other temporal entities.
- Examples:
  - Mia got up$_{e1}$ at seven$_{t1}$ in the morning$_{t2}$.
  - Mia stayed home during the summer$_{t3}$ of 2016$_{t4}$.

More Examples

- 2010 CET,
  February 2010 CET,
  February 29, 2010, CET
- 28 January, 2017, 13:45 Greenwich Mean Time
- the fifteenth century
  the summer of 2016

Complex Type

- Temporal entities of the *complex* type, in contrast, are characterized in reference to other temporal entities such as:

  1. their *starts* and *ends* boundaries or
  2. the length of time (temporal distance) between the two temporal intervals related by some temporal relation such as *before* and *after* or *from*.

Two Cases of the Complex Type

1. Bounded Interval:
   An (extended) interval t, delimited either partially or totally by its specific boundaries such as starts, t_i, and ends, t_j:
   $<t, t_i, t_j>$
2. Minimal Interval delimited by Oriented Span (Relational Time):
   A (minimal) interval t, delimited by its distance d between the two r-related times, t_i and t_j, that are oriented either forward or backward: $<t, t_i, t_j, d, o, s>$,
   where o is the orientation of d towards its start or end by a temporal signal s.

Examples of the Complex Type

Bounded Intervals:

- from Wednesday through Saturday
- from two o'clock to four in the afternoon

Minimal Intervals delimited with Oriented Spans:

- half an hour before midnight
- a week after Christmas
- two years from now
- five hours ago

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Four Types of Temporal Signals

- Atomic Type
  1. Locative signals <loSignal> for positional times (dates, periods, and times of the day): *at, in, on, by, during*
  2. Measure signals <meSignal> for time amounts or lengths: *for, in*
- Complex Type
  1. Boundary signals <boSignal> for bounded temporal intervals (durations): *from – to/through*
  2. Orientation signals <orSignal> for minimal intervals (relational points) delimited with an oriented distance between an event time and a reference time or event: *before, after, from*.

Locative Signals: Examples

1. Mia arrived *at*$_{loSignal}$ *nine-fifteen*. (occurrence: clock-time)
2. Mozart lived *in*$_{loSignal}$ *the eighteenth century*. (state: period of time)

Locative Signals: Interpretation

- The locative signals *at* and *in* each anchor an eventuality to an atomic-type time.
- These anchoring relations can be represented logically with the predicates *occurs* and *holds*.
- Examples:
  - Mia arrived$_{e1}$ at$_{loS1}$ nine-fifteen$_{t1}$.
    $[arrive(e_1) \wedge past(e_1) \wedge occurs(e_1, t)$
    $\wedge\ tOt_1 \wedge hour(t_1) \wedge clocktime(\mathrm{KST}, t_1) = 9:15]$
  - Mozart lived$_{e_2}$ *in*$_{loS_2}$ [the eighteenth century]$_{t_2}$.
    $[live(e_2) \wedge past(e_2) \wedge holds(e_2, t) \wedge$
    $t \subset t_2 \wedge century(t_2) \wedge period(\mathrm{CE}, t_2) = 18]$

Locative Signals: Constraints

- The locative signals like *at*, *on*, and *in* require constraints between an event time interval and a reference time.
  1. The *occurs* relation is constrained by the overlap relation O.
  2. the *holds* relation is constrained by the subinterval relation $\subset$.
- These constraints allow the interpretation of either a shorter or an extended interval to which an eventuality is anchored.

More Examples

1. We preferred traveling$_{e3}$ by/during the$_{loS3}$ night$_{t3}$.
   $[travel(e_3) \wedge occurs(e_3, t) \wedge t\, O\, t_3 \wedge time(t_3) \wedge partOfDay(t_3, \mathrm{NI})$
2. We stayed$_{e4}$ up during the night$_{t4}$].
   $[stay(e_4) \wedge past(e_4) \wedge holds(e_4, t) \wedge t \subset t_4 \wedge time(t_4) \wedge partOfDay(t_4, \mathrm{NI})]$

Measure Signals: Temporal Measures

- Length of Time:
  timeLength is a function $l: I \rightarrow R \times U$,
  where I is a set of time intervals, R a set of reals and U a set of temporal units.
  1. *Classes each last* for_{meS1} *50 minutes*.
  2. *John ran a hundred meters* in_{meS2} *ten seconds.*
- Amount of Time:
  timeAmount is a function $\tau: E \rightarrow R \times U$,
  where E is a set of eventualities, R a set of reals, and U a set of temporal units.
  - *I taught* for_{meS3} *12 hours in April.*
- Note:
  Unlike lengths of time, time amounts can be cumulative.

Temporal Distance

- A temporal distance is a measure relation between two intervals: $distance(t_1, t_2)$.
- This measure is represented by the length of an interval t bounded by its *start* and *end*.
- Definition:
  Given two intervals t_1 and t_2, the *distance* between two intervals t_1 and t_2 is the length of an interval t such that $starts(t_1, t)$ and $ends(t_2, t)$.
  $distance(t_1, t_2) =_{df} length(t) \leftrightarrow [starts(t_1, t) \wedge ends(t_2, t)]$
- Neither the distance nor the length depends on the directionality of an interval. Hence, a distance can be measured from its *start* to *end* or the other way around.

Boundary Signals: Bounded Intervals

1. Mia slept$_{e1}$ from$_{boS1}$ morning$_{t1}$ till$_{boS2}$ noon$_{t2}$.
2. $[sleep(e_1) \wedge past(e_1) \wedge holds(e_1, t) \wedge t \subset t_3 \wedge starts(t_1, t_3) \wedge ends(t_2, t_3)]$

Figure: Bounded Interval

Boundary Signals: Semi-Bounded Intervals

1. She will be working$_{e1}$ till$_{boS1}$ nine o'clock$_{tr}$. $\emptyset_t$
   $[work(e_1) \wedge future(e_1) \wedge holds(e_1, t_e) \wedge ends(t_r, t) \wedge t_e \subset t \wedge time(t_r) \wedge hour(kst, 09:00)]$
2. He has been sleeping$_{e2}$ since$_{boS2}$ two o'clock$_{tr}$. $\emptyset_t$
   $[sleep(e_2) \wedge holds(e_2, t_e) \wedge starts(t_r, t) \wedge t_e \subset t \wedge time(t_r) \wedge hour(kst, 14:00)]$

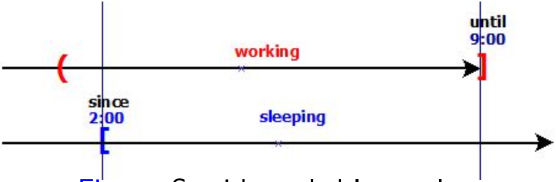

Figure: Semi-bounded Intervals

Minimal Intervals with Oriented Spans

1. Mia left$_{e3}$ home an hour$_{t6}$ after$_{s1}$ her breakfast$_{e4}$.
2. $[leave(e_3) \wedge occurs(e_3, t_3) \wedge length(t_6) = <1, hour> \wedge starts(t_i, t_6) \wedge ends(t_j, t_6) \wedge breakfast(e_4) \wedge occurs(e_4, t_4) \wedge t_4 O\, t_i \wedge t_3 O\, t_j]$

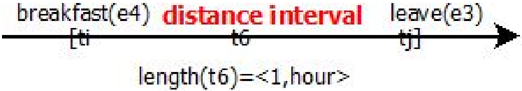

Figure: Temporal Distance-1

Another Example

1. Mia was fourteen$_{e5}$ two weeks$_{t7}$ ago$_{s2}$.
2. $[fourteen(e_5) \wedge occurs(e_5, t_5) \wedge length(t_7) = <2, week>$ $\wedge starts(t, t_7) \wedge ends(t', t_7) \wedge t_5 O\, t \wedge t' O\, n]$

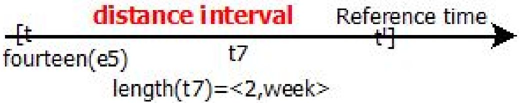

Figure: Temporal Distance-2

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Table: Four Types of Temporal Signals Summarized

signal types	**prepositions**	**time structure**	**sem types**
locative	*at, in, on, by, during*	dates periods	any
measure	*for*	time amounts	state, process
	in	time lengths	transition
boundary	*from – to/till*	bounded intervals	state, process
orientation	*before, after, from*	oriented spans (relational times)	any

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