ISO-TimeML semantics for interlinking annotations

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Abstract

This paper describes a step in the development of a methodology for combining annotation made with different annotation schemes. The methodology, called 'interlinking', assumes that different annotations of the same data will contain certain elements that refer to the same entities. This can be represented by a set of 'identity links' . These links are used for constructing a single, integrated annotation structure at the level of abstract syntax with a semantic interpretation. In this paper we focus on the interlinking of annotations of time and events with ISO-TimeML (ISO 24617-1:2012) and quantification with QuantML (ISO 24617-12:2025). interlinking annotations is in practice only feasible if the respective annotation schemes use the same or convertible representation formalisms. Since QuantML and ISO-TimeML use different formalisms and QuantML has a more fully developed semantics than ISO-TimeML, we developed a new, DRT–based semantics for ISO-TimeML which is presented and discussed in this paper.

Keywords: Semantic annotation, combining annotations, interlinking, QuantML, ISO-TimeML

1. Introduction

This paper reports on activities within the ISO 'preliminary work item' PWI 254617-17, 'Interlinking of annotations using the 'interlinking' approach (Bunt, 2024). which investigates the possibility to combine annotations made with different annotation schemes, This approach has been suggested for the joint application of different parts of the ISO Semantic Annotation Framework ('SemAF'), a family of standards each of which was developed for representing a certain type of semantic information, such as semantic roles, discourse relations, coreference, and information about events, time and space. Combining annotations from different parts would lead to richer, more powerful semantic annotations.

The annotations of two annotation schemes can in principle be combined easily if they are disjoint, resulting in a single annotation if they use the same representation format. This is the case for various SemAF parts, but some parts have domains that are not entirely disjoint. In particular, certain semantic phenomena that form the focus of one SemAF-part often also play a role, albeit of secondary importance, in another. In such a case the application of two annotation schemes results in two annotations that capture partly the same semantic information in different and possibly incompatible ways.

Early in 2025 a long desired new member was born in the SemAF family. The new member, called QuantML after the markup language that it adopts, was officially registered as ISO 24617-12:2025, Quantification. In view of the ubiquitous nature of quantification phenomena in natural language, the new member was most welcome. QuantML and ISO-TimeML exemplify the phenomenon of application domains that are not entirely disjoint. Consider, for example, the sentence *"Most of the guests arrive on Friday"*. Using QuantML, this sentence is analysed as expressing the occurrence of *arrive* events with guests as agents and with Friday as the entity that plays the semantic role *Time*. In ISO-TimeML, by contrast, events are viewed as anchored in time with special temporal relations such as *before, during, simultaneous*, and *included*. The combination of annotations of these two schemes is therefore not straightforward, while it would be very interesting because of their joint coverage of aspects of meaning. This paper explores the use of interlinking for combining annotations of these two schemes, with a focus on the semantic interpretation of the combined annotations.

The paper is structured as follows. Section 2 describes the interlinking approach in relation to the architecture of SemAF parts. Section 3 summarizes those aspects of QuantML and ISO-TimeML that are of particular interest for interlinking. Section 4 presents the semantic interpretation of ISO-TimeML annotations using the same DRT-based framework as used in QuantML. Section 5 discusses the semantic interpretation of interlinked QuantML - ISO-TimeML annotations. Section 6 closes with concluding remarks. Finally, Appendix A contains a detailed example of interlinking the annotations of the two schemes.

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2. Interlinking

Interlinking aims at combining the annotations of textual, spoken or multimodal data according to different parts of the SemAF family without altering the original annotations. It exploits the fact that the two (or more) separate scheme-specific annotations apply to the same source material by identifying the elements in these annotations that refer to the same semantic entity and adding identity links between these elements.

In order to see what is involved in interlinking annotations of two SemAF parts, we consider the architecture of a SemAF scheme as shown schematically in Fig. 1. The following three levels are distinguished:

- the concrete syntax, which specifies a representation format. Any representation format that is expressive enough can be chosen (see Fig. 1), but XML is most commonly used In SemAF.
- the abstract syntax, which expresses the semantically relevant information of the annotations in the form of pairs, triples, and other set-theoretical structures.
- the semantics, which defines the meaning of annotations in terms of representations with a well-defined semantics.

These levels are interrelated through decoding and interpretation functions.

At the level of concrete syntax, interlinking consists of adding identity links between components of representations from different schemes. This is a rather straightforward matter (although there may be some issues in the identification and use of markables). The real challenges lie at the other two levels. In particular, sitting in between the levels of concrete representation and semantics, the combination of annotations at the level of abstract syntax faces a dual challenge. On the one hand, the expressions at this level should have a systematic encoding-decoding relation to concrete representations; on the other hand they should capture the information contained in the combined annotations in a way that allows their joint semantic interpretation.

Since ISO-TimeML and QuantML are two of the best developed and most complex SemAF parts, a sensible strategy for exploring the possibilities and limitations of interlinking is to explore the possible combination of their respective annotations, in particular at the levels of abstract syntax and semantics.

Table 1 indicates the development of applying the interlinking approach to ISO-TimeML and QuantML. Both schemes have a fully developed concrete syntax with XML-based reference representation format. QuantML is also fully developed at the other levels and their interrelations. ISO-TimeML, being the oldest SemAF part, has a partially developed abstract syntax and lacks the specification of a decoding function; proposals for these components have been presented in Bunt et al. (2025) together with the abstract syntax and decoding function for interlinking elements. At the level of semantics and interpretation function, ISO-TimeML is partly developed and uses different forms of semantics than QuantML. This paper aims to provide the remaining ingredients for effective interlinking by (1) defining a semantics for ISO-TimeML annotations in the same DRT-based style as the QuantML semantics (Section 4), and (2) outling the semantic interpretation of integrated annotation structures (Section 5).

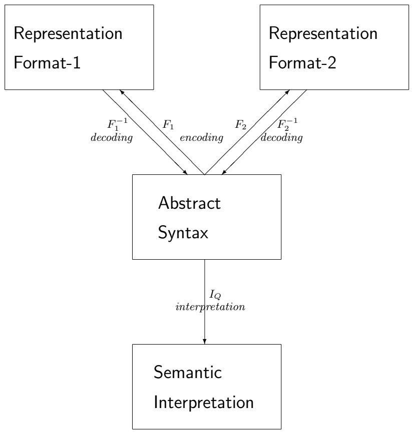

Figure 1: Levels and interrelations in SemAF annotation schemes.

	ISO-Time TimeML	QuantML	Inter-linking
concrete syntax	√	√	√
decoding	1	√	1
abstract syntax	1	√	1
inter-pretation	2	√	2
semantics	2	√	2

Table 1: √ = done before start of PWI, 1 = presented in XXXX (YYYY), 2 = topic of this paper

3. Two linked annotation schemes

3.1. Theoretical background

The ISO-TimeML and QuantML annotation schemes are both theoretically rooted in Davidsonian event semantics (Davidson, 1967; Parsons, 1990) in which verbs are viewed as denoting events with participants (rather than as predicates with arguments). This view is extended in ISO-TimeML, acknowledging that certain nouns, like *"concert", "meeting"* and certain adjectives *"the dormant volcano"* also denote events. The focus is on the temporal anchoring of events and on temporal relations among events, as expressed by temporal, aspectual and subordination relations.

QuantML, on the other hand, focuses on the involvement of participants in events. Participants have semantic roles, like *Agent* and *Theme*, and may be involved individually as well as collectively. Time of occurrence is treated as a participant which is a temporal object, with *Time* as semantic role. Quantification arises when a participant is not a single individual but a set of individuals or when a verb or other event-denoting expression does not refer to a single event but to a set of events, which may be quantified over (as in *"Tom called twice every Sunday"*).

ISO-TimeML additionally takes inspiration from the general framework of Allen's algebra of temporal intervals (Allen, 1984), which uses 13 relations between intervals, including equality. For QuantML, the main source of inspiration has been the theory of generalised quantifiers (GQT, Barwise and Cooper, 1981, Cooper, 1983). In this theory, natural language quantifiers are (mostly) NPs like *"Each of the students"* and *"Three kilos of sugar"*.

QuantML supports the annotation of quantified participation in events by taking into account the following categories of information:

(1)
1. quantification domain
2. determinacy (determine/indeterminate)
3. distributivity (individual/collective/ unspecific)
4. individuation (count/mass)
5. involvement (absolute and proportional)
6. semantic role
7. exhaustivity
8. polarity
9. relative participant scopes
10. event scope
11. repetitiveness
12. size of reference domain
13. restrictiveness of modifiers
14. linking of modifiers (inverse or linear)

These categories correspond to attributes of XML elements in the concrete syntax of QuantML. Some of these attributes are optional and have a default value: polarity is by default 'positive', exhaustivity is 'negative', event scope is 'narrow', and repetiveness is 'at least once'. For explanations and discussion of all the categories see.(Bunt, 2020) and ISO (2025).

3.2. Concrete syntax

QuantML and ISO-TimeML both have a concrete syntax that defines a reference representation format using XML. While in the SemAF architecture shown in Figure 1 (See ISO 2015) the choice of representation format is of secondary importance, having the same representation format facilitates the interlinking at the level of concrete syntax. This is illustrated in (2), which shows an interlinked annotation, consisting of three parts: (1) the ISO-TimeML annotation, (2) the QuantML annotation, and (3) the identity statements that link the two.

(2) Some of the students will protest on Friday.

Markables:
m0 = "Some of the students will protest on Friday", m1 = "Some of the students", m2 = "the students", m3 = "students", m4 = "will protest", m5 = "on Friday"

```
<linkedRep> xml:id="tq1" target="#m0">
  <tmeML xml:id="crT">
    <EVENT xml:id="eT1" target= "#m4" pred=
      "protest" class="OCCURRENCE" type=
      "PROCESS'"/>
    <TIMEX3 xml:id="tT1" target= "#m5"
      type="DATE" value="XXXX-YY-05"/>
    <TLINK eventID="#eT1" relatedToTime=
      "#tT1" relType="IS-INCLUDED"/>
    </timeML>
 <quantML xml:id="crQ">
    <event xml:id="eQ1" target="#m4"
      pred="protest"/>
    <entity xml:id="xQ1" target="#m1" ref-
      Domain="#xQ2" individuation="count"
      involvement="some"/>
    <refdomain txml:id="xQ2" target="#m2"
      pred="student" determinacy="det"/>
    <participation event="#eQ1"
      participant="#xQ1" semRole="agent"
      distr="collective" evScope="narrow" />
    <entity xml:id="xQ3" target="#m5" ref-
      Domain="#xQ4" individuation="count"
      involvement="some"/>
    <refdomain xml:id="xQ4" target="#m5"
      pred="friday" determinacy="det"/>
    <participation event="#eQ1"
      participant="#xQ3" semRole="time"
      distr="individual" evScope=
      "narrow"/>
    </quantML>
 <idL xml:id="crIL">
  <idLink xml:id="i1" arg1="#eQ1" arg2="#eT1"/>
```

<idLink xml:id="i2" arg1="#xQ2" arg2="#tT1"/>
</idL>
</linkedRep>

A linked annotation structure can be represented schematically as follows, where X_T and X_Q are the linked ISO-TimeML and QuantML annotations, and X_{IL} is the set of linking identity specifications.

(3) <linkedRep> xml:id="tq1" target="#m0">
X_T
X_Q
X_{IL}
</linkedRep>

The example shows how QuantML uses the core elements <event>, <entity> and <participation> for representing semantic information about participants and the way they participate in events. In addition, QuantML has a number of elements for representing modification by adjectives, prepositional phrases, possessive phrase, and relative clauses occurring in natural language expressions that describe quantified participants.

ISO-TImeML uses the core elements <EVENT>, <TIMEX3> and <TLINK> for representing information about events, temporal objects and temporal relations, respectively. Three types of temporal objects are distinguished: instants, dates, and periods, which are all represented by <TIMEX3> elements with different values of the @TYPE attribute and with different attributes depending on the @TYPE value.

From a semantic point of view, the elements <TIMEX3> and <TLINK> are rather overloaded. For example, a <TLINK> element is used to represent the relation between an event and its time of occurrence, or a temporal relation between events, or a temporal relation between periods. This causes ambiguities for their decoding into abstract annotation structures.

3.3. Abstract syntax and decoding

The specification of an abstract syntax consists of (1) a list of primitive concepts, called the 'conceptual inventory', and (2) the recursive specification of annotation structures in the form of set-theoretic structures like pairs and triples.

The conceptual inventory of ISO-TimeML contains the following time-related basic concepts (1) named temporal objects like *January, Christmas*; (2) temporal relations, subordination relations, and aspectual relations, like *during, before, conditional, initiates*; and (3) units for measuring durations, like *hour, minute, day,*

The conceptual inventory of QuantML includes (1) quantitative and proportional predicates such as *some, several, most*; (2) dimension predicates such as *weight, length, volume* and corresponding units of measurement; (3) the possessive relation 'Poss' (due to Peters & Westerståhl, 2013).

In addition, both conceptual inventories contain (1) predicates that correspond to (senses of) natural language content words, such as *teach, concert, student*; (2) linguistic categories like *process, past, mass, indeterminate*; (3) the real numbers and numerical relations like *greater than*.

The structures defined by the abstract syntax come in two forms: (a) *entity structures*, which contain semantic information about a stretch of source data, and (b) *link structures*, which express semantic relations between two or more entity structures.

The variety of ways of representing temporal objects in the concrete syntax of ISO-TimeML requires a way of distinguishing different types of n-tuples with different meanings, as illustrated by example (4). In (4a) the phrase *"two hours before lunch"* designates an instant at a certain distance in time from an event, while in (4b) it indicates a period of a certain length. This means that the corresponding triples of the abstract syntax should be interpreted differently. In order to enable this, we introduce the use of labels such as *inst*, *per* and *val* to mark the semantic type of a structure.

(4) a. Tom arrived two hours before lunch.
⟨*inst* ⟨lunch, ⟨*amt*⟨tdistance, 2, hour⟩, before⟩⟩⟩
b. Tom taught (for) two hours before lunch.
⟨*per* ⟨lunch, ⟨*amt*⟨tdistance, 2, hour⟩, before⟩⟩⟩

Apart from the introduction of labels, the abstract syntax and the decoding of concrete representations into abstract annotations of ISO-TimeML are as defined in (NN4)). We add labels in the same way to the annotation structures of QuantML. For identity statements of the interlinking we use the label *id*. Example (5) illustrates this.

Using labels in the abstract syntax has the effect shown in (5) when the decoding functions dF_T of ISO-TimeML (see Bunt et al, 2025) and dF_Q of QuantML are applied to the annotation representation of the sentence *"John called at midnight"*, which is analysed in detail in Appendix A. This formulation of the decoding functions makes use of an auxiliary function, $IdEl$, which, applied to an annotation representation X of the concrete syntax, selects the element with identifier x_i. For example, $IdEl(X_{IL}, i2)$ = <idLink xml:id="i2" arg1="#xQ2" arg2="#tTt"/>.

(5) **a. QuantML**
A$_Q$ = $dF_Q(X_Q) = \langle \epsilon_{Qe}, \langle \epsilon_{xQ1}, \epsilon_{xQ2} \rangle, \langle pL_{Q1}, pL_{Q2} \rangle, \langle scL_1 \rangle \rangle$
$\epsilon_{Qe} = dF_Q$(IdEl(X_Q, e_Q)) = ⟨*evq*, ⟨call, past⟩⟩
$\epsilon_{Qx1} = dF_Q$(IdEl($X_Q, xQ1$))
⟨*ent*, ⟨student, determinate, count⟩⟩
$\epsilon_{xQ2} = dF_Q$(IdEl($X_Q, xQ2$))

$\langle$*ent*, $\langle$midnight, determinate, count, 1$\rangle\rangle$
pL_{Q1} = $\langle$*pLink*, $\langle\epsilon_{Qe}$, ϵ_{Qx1}, agent, individual$\rangle\rangle$
pL_{Q2} = $\langle$*pLink*, $\langle\epsilon_{Qe}$, ϵ_{Qxt}, time, individual$\rangle\rangle$,
scL_{Q1} = $\langle$*scope*, $\langle pL_{Q1}, pL_{Q2}$,wider$\rangle\rangle$

b. ISO-TimeML
$\mathsf{A}_T = dF_T(X_T) = \langle\epsilon_{Te}, \langle\epsilon_t\rangle, \langle tL_1\rangle\ \langle\rangle\rangle$
$\epsilon_{Te} = dF_T(IdEl(X_T, e_t))$
= $\langle$*evt*, $\langle$call, occurrence, transition, past$\rangle\rangle$
$\epsilon_{Tt} = dF_T(IdEl(X_T, tT1)$ = $\langle$*inst,* $\langle$T00:00$\rangle\rangle$
tL_{T1} = $\langle$*tLink*, $\langle\epsilon_{Te}$, ϵ_{Tt}, included$\rangle\rangle$

c. Interlinking:
$\mathsf{A}_{IL} = dF_{IL}(X_{Il})$
= $\langle dF_{IL}(\mathrm{IdEl}(X_I, i1), dF_{IL}(\mathrm{IdEl}(X_{IL}, i2))\rangle$
= $\langle\langle\epsilon_{Qe}, \epsilon_{Te}\rangle, \langle\epsilon_{xQ2}, \epsilon_{Tt}\rangle\rangle$

The interlinking of QuantML and ISO-TimeML annotations includes the construction of an integrated abstract annotation structure from the two concrete annotation representations and their decodings. To this end a function dF_{QT} is defined which combines the results of the decoding functions dF_Q and dF_T, plus the function dF_{IL} defined for the <*idLink*> structures.

This latter function embodies a key aspect of the interlinking approach, namely that identity statements correspond to pairs of the entity and event structures involved. The function dF_{QT} substitutes these pairs for their elements in link structures (participation structures, scope relations structures, and temporal as well as subordination and aspectual relation structures). Auxiliary functions (PLink, ScopeLink, SubLink, and AspLink) implement this for the various types of link structures.

PLink, for example, combines two participation link structures into a single link structure in which the participants of the two arguments are paired, their semantic roles are paired, and their parameters, extracted by the auxiliary function Params, are checked for being compatible. These parameters are the distributivity, event scope, exhaustiveness and polarity which occur in a participation link structure. Example (6) illustrates this.

(6) **Interlinked annotation structure:**
$\mathsf{A}_{QT} = \langle\epsilon_e, \epsilon_x, pL, scL\rangle$, where
$\epsilon_e = dF_{IL}(\mathrm{IdEl}(X_{Il}), i1) = \langle\epsilon_{Qe}, \epsilon_{Te}\rangle$
$\epsilon_x = \langle dF_{QT}(\epsilon_{Qx1}), dF_{QT}(\epsilon_{xQ2}), dF_{QT}(\epsilon_{Tt})\rangle$
$= \langle\epsilon_{Qx1}, \langle\epsilon_{xQ2}, \epsilon_{T1}\rangle\rangle$
$=_D \langle\epsilon_1, \epsilon_2\rangle$
$pL = \{pL_1, pL_2\}$
$pL_1 = pL_{Q1}$
pL_2 = PLink($\langle pL_{Q2}, tL_{T1}\rangle$) =
= $\langle\epsilon_e, \epsilon_2$, $\langle$SRole(pL_{Q2}), SRole(tL_{T1}),
Params(pL_{Q2})$\rangle$
= $\langle\epsilon_e, \epsilon_2$, $\langle$time, simultaneous$\rangle$,
$\langle$individual, narrow, non-exh,
positive$\rangle\rangle$
$scL = \{dF_{QT}(scL_{Q1}\})\rangle$

4. ISO-TimeML semantics using DRT

In this section we develop a semantic interpretation-by-translation for ISO-TimeML annotations in terms of second-order discourse representation structures (DRSs, Kamp & Reyle 1993). The discourse referents in this semantics are non-empty sets of individuals (events and temporal objects included). We use a simplified linear notation for DRSs, for example, [X | x ∈ X → α], suppressing the condition |X| ≥ 1.

To keep the semantics as simple as possible, the elements of the conceptual inventories are assumed to be available as building blocks of semantic representations under the same name, therefore: $I_T(c) = c$ and $I_Q(c) = c$.

4.1. Event structures

An event structure is a labeled 6-tuple $\langle evt$, $\langle$P, Ty, C, Te, As, V$\rangle\rangle$, consisting of an event predicate, an event type, an event class, a tense, an aspect, and a veracity. Semantic interpretation:

$I_T(\langle evt$, $\langle$P, T_y, C, Te, As, positive$\rangle\rangle$) =
= [E | e ∈ E → P(e), Ty(e), C(e), Te(e), As(e))]

$I_T(\langle evt$, $\langle$P, T_y, C, T, A, negative$\rangle\rangle$) =
= ¬[E | e ∈ E → P(e), Ty(e), C(e), Te(e), As(e))]

Example: "wrote":
$I_T(\langle evt$, $\langle$write, occurrence, process, past, imperfective,
positive$\rangle\rangle$ =
= [E | e ∈ E → write(e), occurrence(e), process(e),
imperfective(e), past(e)]

4.2. Temporal entities

Temporal entities fall into six categories: (1) instant, (2) date, (3) period, (4) set of any of these, (5) amount of time, and (6) frequency. Entities of the respective categories are distinguished in the abstract syntax by the labels *inst, date, per, qset, amt* and *freq*. Formally, a label can be viewed as just an additional element in an n-tuple, so in the abstract syntax all entity structures have the form $\langle$type, P$\rangle$, where ‘P’ is a sequence of properties.

Named temporal entities can be divided into those that function exclusively as proper names and hose that can additionally be quantified over. The first category contains calendar years and clock times, the second contains calendar months (*“January"*), calendar weekdays (*“Wednesday"*), and named special days (*“Christmas", “Thanksgiving"*). ‘For the use as a proper name, as in (7a), ISO-TimeML annotation makes use in the concrete syntax of the @temporalFunction attribute, giving it the value “TRUE" to indicate that a specific temporal entity has to be determined in a postprocessing stage. The abstract syntax and semantics of a named temporal entity used as a quantifier is illustrated in (7b,c).

(7) a. *"Friday"* used as a proper name:
"Jelle will graduate on Friday"
A_T = $\langle date$,⟨*val*,⟨day, friday⟩⟩⟩
Semantics:
$I_T(A_T)$ = [X | $|X|$=1, x ∈ X → day(x)=friday$_0$], where 'friday-0' is the specific friday calculated in postprocessing.

b. *"Friday"* used as an existential quantifier:
"Most students graduate on (a) Friday":
A = ⟨$qset$, ⟨*val*⟨day, friday⟩, some⟩⟩
Semantics:
$I_T(A_T)$ = [X| x ∈ X → day(x)=friday]

c. *"Friday"* used as a universal quantifier:
"Bill teaches every Friday":
A = ⟨$qset$, ⟨*val*⟨day, friday⟩, all⟩⟩
Semantics:
$I_T(A_T)$ = [X| x ∈ X ↔ day(x)=friday]

In the remainder of this section we specifiy the semantic interpretation of the annotations of the six categories listed above.

4.2.1. Instants

The four possible forms of an instant structure have the following semantic interpretation.

1. A single clock time: a constant, such as "16:45" or *"midnight"*. Semantic interpretation:
I_T(⟨*inst*, t_1⟩) =
= [T | t ∈ T → clocktime(t) = I_T(t_1)]
= [T | t ∈ T → clocktime(t) = t_1]

2. A labeled pair ⟨day name, clock time⟩⟩:
I_T(⟨*inst*, ⟨$d_1 t_1$⟩⟩) =
= [T | t ∈ T → [day(t) = I_T(d_1),
clocktime(t) = I_T(t_1)]

3. A labeled triple ⟨instant, amount of time, relation⟩ or ⟨*inst*, ⟨event, amount of time, relation⟩⟩ (*"half an hour before midnight/departure'*).

The interpretation of such a triple makes use of a temporal instance of the 'glue merge' operation defined in QuantML, where it is used to interpret participation link structures. This operation is defined as follows:

$\cup^t$(t_1, a_1, R_1) = $[T|t \in T \rightarrow [X|x \in X \rightarrow$
$I_T(t_1)(x)$, $I_T(a_1)(t,x)$, $I_T(R_1)(t,x)]]$

Using this operator:
I_T(⟨*inst*, ⟨t_1, a_1, R_1⟩⟩) = $\cup^t$(I_T(t_1), I_T(a_1), I_T(R_1))

Example: *"half an hour before midnight."*
I_T(⟨*inst*⟨midnight$_0$, ⟨*amt*, ⟨tdistance, 0.5, hour⟩⟩,
before⟩⟩ =
= [T | t ∈ T →] [Z | $z \in Z$ → clocktime(z)=T00:00,
before(t, z)), tdistance((t, z), hour) = 0.5]]

4.2.2. Dates

Date structures, having four possible forms, have the following semantic interpretation.

1. A labeled triple ⟨*date*, ⟨year, month, day⟩⟩:
I_T(⟨*date*, ⟨y1, m1, d1⟩⟩ =
= $[T|\ t \in T \rightarrow$ year(t) = $I_T(y1)$,
month(t) = $I_T(m1)$, day(t) = $I_T(d1)$]

Example:
I_T(⟨*date*, ⟨2025, may, 25⟩⟩⟩)
= $[T|\ t \in T \rightarrow$ year(t) = 2025, month(t) = may,
day(t) = 25]

2. A labeled pair ⟨year, month⟩ (*"May 2026"*).
I_T(⟨*date*, t⟨y1, m1⟩⟩ =
= $[T|\ t \in T \rightarrow$ year(t) = $I_T(y1)$, month(t) = $I_T(m1)$]
Example:
I_T(⟨*date*, ⟨⟨*val*, ⟨year, 2026⟩⟩, ⟨*val*⟨month, may⟩⟩⟩⟩)
= $[T|\ t \in T \rightarrow$ year(t) = 2026, month(t) = may

3. A labeled pair ⟨month, day number⟩:
I_T(⟨*date*, ⟨m1, d1⟩⟩ =
= $[T|\ t \in T \rightarrow$ month(t) = $I_T(m1)$, day(t) = $I_T(d1)$]

Example: (*"December 25"*)
I_T(⟨*date*, ⟨december, 25⟩⟩)
= $[T|\ t \in T \rightarrow$ day(t) = 25, month(t) = december]

4. A labeled pair ⟨week, day name⟩:
I_T(⟨*date*, ⟨w1, d1⟩⟩ =
= $[T|\ t \in T \rightarrow$ week(t)=$I_T(w1)$,dayname(t)=$I_T(d1)$]

Example: (*"week 20 on Tuesday"*).
I_T(⟨*date*, ⟨w20, tuesday⟩⟩)
= $[T|\ t \in T \rightarrow$ week(t) = w20, dayname(t) = tuesday]

4.2.3. Periods

The semantics of period structures makes use of an auxiliary function 'AbsInt' which, given a DRS $]A|C_1, a \in A \rightarrow \alpha]$ and a binary relation R, moves the relation inside the DRS while introducing a lambda abstraction as follows:
AbsInt($]A|C_1, a \in A \rightarrow \alpha], R$) =
= $\lambda x.]A|C_1, a \in A \rightarrow \alpha, R(x,a)]$.

Using this function, the possible forms of period structures have the following semantic interpretation.

1. A labeled pair ⟨begin point, end point⟩:
I_T(⟨*per*, ⟨t1, t2⟩⟩ =

= $[T|\ t \in T \rightarrow$ AbsInt(I_T(⟨*inst*, ⟨t1⟩⟩)(t), begin),
AbsInt(I_T(⟨*inst*, ⟨t2⟩⟩)(t), end)]

Example: *From two to five on January first"*.
I_T(⟨*inst*, ⟨*date*,⟨january,1⟩, T14:00⟩,
⟨*inst*, ⟨*date*,⟨january,1⟩,T17:00⟩⟩) =
= $[T|\ t \in T \rightarrow$ month(t) = january,
datynumber(t)=1, $[Y, Z|y \in Y \rightarrow$ clocktime(y) = 14:00, included(z, x), begin(t, y)], $z \in Z \leftrightarrow$ clocktime(z) = 17:00, included(z, x), end(t, z)]]

2. A labeled triple ⟨instant, time amount, relation⟩, formed by the beginning or end of the period, its length, and the relation 'before' or 'after' .

   Example:
   "the last two weeks before Christmas"
   I_T(⟨*per*, ⟨christmas, ⟨*amt*, ⟨tdistance, 2, week⟩⟩, before⟩) =
   = $[T|\ t \in T \rightarrow$ before($t1$, christmas),
   distance(t, christmas) $\leq$ 2]

3. Like the previous case, but with an events as begin/end rather than an instant, as in *"the first two days after the attack"*. The semantics is analogous.

4.2.4. Time-amount structures

A time-amount structure is a labeled triple ⟨*amt*, ⟨dimension, rational number, temporal unit⟩⟩:
I_T(⟨*amt*, ⟨D, k, u⟩⟩ = $\lambda x.D(x, u) = k$.

Example: *" half an hour"*.
I_T(⟨*amt*,⟨tdistance, 0.5, hour⟩⟩) =
λx. tdistance(x,hour)= 0.5.

4.2.5. Frequency structures

A frequency is either a labeled natural number ⟨*freq*, n⟩ for *"twice"*, etc.) or a labeled pair ⟨*freq*, ⟨natural number, temporal unit⟩⟩ (*"twice a week"*).

Semantics:
I_T(⟨*freq*, k⟩) = $[T|t \in T \rightarrow [E||E| = k, e \in E \rightarrow$ included(e, t)]]

I_T(⟨*freq*, ⟨k, u⟩⟩) = $[T|t \in T \leftrightarrow I_T(u)(t), t \in T \rightarrow$ $[E||E| = k, e \in E \rightarrow$ included(e, t)]]

4.2.6. Quantification structures

A quantification structure corresponds to a <TIMEX3> element of type "SET". From a semantic point of view, such elements contain information about three aspects of a quantification: (1) a quantifier in the sense of classical logic, expressed by the @quant values "EVERY" and "SOME", (2) a domain that the quantifier ranges over, indicated by the @value attribute, and (3) repetitions of an event indicated by the optional attribute @freq.

For the abstract syntax this means that a quantification structure is either a labeled pair ⟨*qset*, ⟨domain, quantifier⟩⟩ or a labeled triple ⟨*qset*, ⟨domain, quantifier, frequency⟩⟩.

Semantics:
1. I_T(⟨*qset*, ⟨D, some⟩⟩) = $[T|t \in T \rightarrow D(t)]$
2. I_T(⟨*qset*, ⟨D, all⟩⟩) = $[T|t \in T \leftrightarrow D(t)]$
3. I_T(⟨*qset*, ⟨D, some, f⟩⟩) = $[T|\ t \in T \rightarrow D(t)$, $[E|\ I_T(f)(E), e \in E \rightarrow$ included(e, t)]]
4. I_T(⟨*qset*, ⟨D, all, f⟩⟩) = $[T|\ t \in T \leftrightarrow D(t), t \in T \rightarrow$ $[E|\ I_T(f)(E), e \in E \rightarrow$ included(e, t)]]

Examples:
1. *"Friday"* used as an existental or universal quantifier, see examples in (7).
2. Quantification with frequency, as in *"twice a week"*:
   I_T(⟨*qset*, ⟨week, all, ⟨*freq*,2⟩⟩⟩) = $[T|\ t \in T \leftrightarrow$ $week(t)$, $t \in T \rightarrow [E||E|$=2,$e \in E \rightarrow$ included(e, t)]]

4.3. Link structures

The abstract syntax of ISO-TimeML has seven different link structures, distinguished by labels: for (1) anchoring events in time (label *etRel*); (2) temporal ordering of events (*eteRel*, (3) ordering of periods, dates or instants relative to each other (*ttRel*); (4) measuring a time interval (*tmRel*); (5) specifying subordination relations between events (*esRel*); (6) indicating aspectual relations between events (*eaRel*), and (7) quantified temporal anchoring a set of events (*qtRel*). Their semantics is as follows.

a. Temporal anchoring: I_T(⟨*etRel*,⟨e_1, t_1, R⟩⟩) =
$\cup^+(I_T(t_1), I_T(e_1), [T|t \in T \rightarrow$
$[E|e \in E \rightarrow I_T(R)(e,t)]])$

b. Temporal event relations:
I_T(⟨*eteRel*⟨e_1, e_2, R⟩⟩) =
$\cup^+(I_T(e_1), I_T(e_2), [E1|e \in E1 \rightarrow$
$[E2|e' \in E2 \rightarrow I_T(R)(e, e')]])$

c. Intra-time relations:
I_T(⟨*ttRel*, ⟨t_1, t_2, R⟩⟩) =
$\cup^=(I_T(t_1), I_T(t_2), R)$

e , f. Aspectual and subordination relations: identical to temporing anchoring:
I_T(⟨*eaRel*,⟨e_1, e_2, R⟩⟩) =
I_T(⟨*esRel*,⟩⟨e_1, e_2, R⟩⟩) =
$\cup^+(I_T(e_1), I_T(e_2), [E1|e \in E1 \rightarrow$
$[E2|e' \in E2 \rightarrow I_T(R)(e, e')]])$

g. Quantified temporal anchoring:
I_T(⟨*qtRel*,⟨E_Q, T_Q, R⟩⟩) =
$\cup^+(I_T(t_1), I_T(e_1), [T|t \in T \rightarrow$
$[E|e \in E \rightarrow I_T(R)(e,t)]])$
Example: *"Carl teaches thrice a week"*:
$\cup^+$ (I_T(⟨*qset*, ⟨week, all, ⟨*freq*, 3⟩⟩⟩, $[T|\ t \in T \leftrightarrow$ week(t), I_T(⟨*evt*, ⟨teach, occurrence, process⟩⟩, included) =

= $[T|t \in T \leftrightarrow$ week(t), $t \in T \rightarrow [E||E| = 2$,
$e \in E \rightarrow$ teach(e), occurrence(e), process(e),
included(e, t)]]

5. Interlinked annotation semantics

The implementation of QuantML - ISO-TimeML interlinking includes the construction of an integrated abstract annotation structure from the decodings of the two concrete representations. To this end a function dF_{QT} is defined which combines the results of the decoding functions dF_Q and dF_T, plus the decoding function dF_{IL} applied to the <*idLink*> structures - see (5d).

In QuantML, an annotation structure is a quadruple $\langle \epsilon_{eQ}, S_Q, pL_Q, scL_Q \rangle$ consisting of an event structure ϵ_e, a set of participant structures S_Q, a set of participation link structures pL_Q, and a set of scope link structures scL_Q. An ISO-TimeML annotation structure is a similar quadruple $\langle \epsilon_{eT}, S_T, L_T, \emptyset \rangle$, with temporal, aspectual, subordinate and measure links instead of participation links, and with S_T containing temporal entities and events. The integrated abstract annotation structure has the same overall structure, with the content described in (8).

(8) $A_{QT} = \langle \epsilon_{eQT}, S_{QT}, L_{QT}, scL_{QT} \rangle$, with:

- $\epsilon_{eQT} = \langle \epsilon_{eQ}, \epsilon_{eT} \rangle$
- S_{QT} is the set of all pairs of entities from S_Q and S_T that are linked through an <*idLink*> element, plus the individual elements of S_Q and S_T that are not linked.
- L_{QT} is the union of the pL_Q and L_T sets of link structures while replacing any linked entity by the pair consisting of that entity and the one that it is linked with.
- $scL_{QT} = scL_Q$

The semantics of the integrated annotation structure is calculated by the interpretation function I_{QT}, following the same approach as the QuantML semantics. This approach uses the information in scope link structures for combining the information in participation link structures, which in turn include the information in the event and participant structures. In QuantML the semantics of annotation structures (as defined by the abstract syntax is therefore simply the semantics of the sequence of participation links, ordered by the scope relations. This can be copied for the semantics of integrated annotations since the decoding function dF_{QT} has replaced the elements in QuantML participation links by interlinked pairs (of events and participant/temporal objects).

The interpretation function I_{QT} is thus defined as follows[1], where the order $pL1, pL_2, ..pL_n$ is determined by the scope relations in scL_Q, interpreted by the functions σ_{ij}.

(9) $I_{QT}(A_{QT}) = I_{QT}(\langle pL_1, pL_2, ..pL_n \rangle) =$
$= \sigma_{12}(I_{QT}(pL_1), \sigma_{23} I_{QT}(pL_2), ...$
$\sigma_{n-1,n} I_{QT}(pL_n))$

Formulating the semantics of ISO-TmeML annotations in the form of a translation to DRSs, like the QuantML semantics, makes it possible to use the operations on DRSs defined in DRT and in QuantML. In addition, the following variant of the 'scoped merge' operation defined in QuantML is used.

Linked merge This operation generalizes the 'scoped merge' operation $\cup^*$ to take into account that the identity relations expressed by interlinking statements lead to pairs of entity structures in the integrated annotation structure, instead of single entity structures.

Scoped merge:
$\cup^*([A|a \in A \rightarrow \alpha], [B|b \in B \rightarrow \beta], R) =$
$= [A|a \in A \rightarrow \alpha, [B|b \in B \rightarrow \beta, R(a,b)]]$

Scoped merge generalized to linked merge:
$\cup^{**}(\langle [A_1|a \in A_1 \rightarrow \alpha_1], [A_2|a \in A_2 \rightarrow \alpha_2] \rangle,$
$[B_1|b \in B_1 \rightarrow \beta_1], [B_2|b \in B_2 \rightarrow \beta_1] \rangle,$
$\langle R_1, R_2 \rangle, \langle \pi_1, \pi_2 \rangle) =$
$= [A|a \in A \rightarrow \alpha_1, \alpha_2, [B|b \in B \rightarrow \beta_1, \beta_2,$
$R_1(a,b), R_2(a,b)]]$

The use of this operation is illustrated by the semantic interpretation of the interlinked annotation structure for the example sentence *"John called at midnight"* in Appendix A. This example shows step by step how the interlinking works, starting from the concrete representation via the integrated abstract annotation structure and down to the semantic representation computed by the combined interpretation functions.

6. Conclusion

With the introduction of labeled n-tuples in the abstract syntax of both QuantML and ISO-TimeML together with the definition of a DRT-based semantics for ISO-TimeML, we have paved the way for effectively combining QuantML and ISO-TimeML annotations (1) at the concrete syntax level by linking representations by means of identity links, (2) at the abstract syntax level by defining a decoding function that constructs an integrated annotation structure, and (3) at the level of semantics by

[1] For more information see ISO 24617-12:2025, Section B.7.

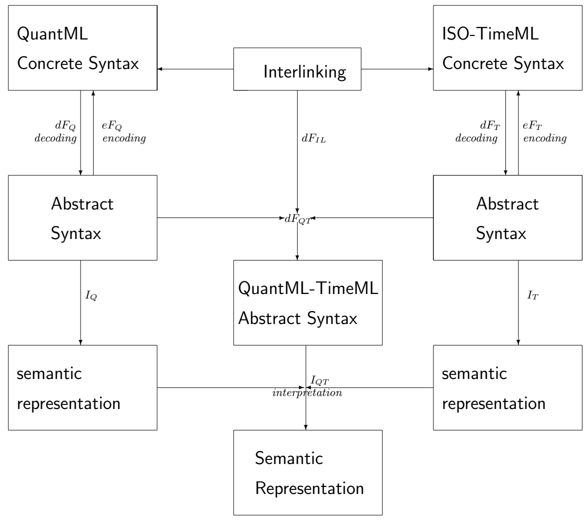

Figure 2: Interlinking of QuantML and ISO-TimeML annotation schemes.

means of operations that combine DRSs into a single integrated DRS. This is visualized in Fig. 2 and illustrated in detail by the example in Appendix A.

The next step in exploring the interlinking of ISO-TimeML and QuantML annotations is to specify the interpretation function I_{QT} systematically and in full detail. Further work also includes the study of some details that have been left out of consideration in this paper, such as the ISO-TimeML attributes @temporalFunction and @functionInDocument.

Another issue to be explored in future work is the interlinking of annotations from other SemAF schemes, such as those for discourse relations and coreference. So far, the development of interlinking as a way to build rich annotations while preserving existing annotated corpora seems promising as the basis for a new initiative to extend the ISO Semantic Annotation Framework.

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Appendix A

In this appendix we show in detail how the use of interlinking combines ISO-TimeML and QuantML annotations at the levels of concrete and abstract syntax, with a decoding function that constructs an integrated annotation structure, and an interpretation that computes the meaning of integrated annotation structures..

(10) *"John called at midnight. "*

Markables:
m0 = "John called at midnight", m1 = "John", m2 = "called", m3 = "at'", m4 = "at midnight", m5 = "midnight"

CONCRETE SYNTAX:

```
<linkedRep> xml:id="tq1" target="#m0">
 <timeml xml:id="crT">
   <EVENT xml:id="eT1"
      target= "#m2" pred="call"
      class="OCCURRENCE"
      type="TRANSITION'"/>
   <TIMEX3 xml:id="tT1" target= "#m4"
      type= TIME" value="XXXX-YY-ZZT00:00"/>
   <SIGNAL xml:id="s1" pred="AT"/>
   <TLINK eventID="#eT1" relatedToTime="#tT1"
      relType="SIMULTANEOUS"/>)
 </timeml>
<quantml xml:id="crQ" target="#m0">
      <event xml:id="eQ1" target="#m4"
        pred="call"/>
      <entity xml:id="xQ1" target="#m1" ref-
        Domain="#xQ2" individuation="count"
        size="1" involvement="all"/>
      <refDomain txml:id="#xQ2" target="#m1"
        pred="John" determinacy="det"/>
      <participation event="eQ1" participant="xQ1"
        semRole="agent" distr="individual"
      '  evScope="narrow" />
      <entity xml:id="xQ3" target="#m3 ref-
        Domain="#xQ4 individuation="count"
        involvement="all" size="1"/>
      <refDomain xml:id="#xQ4" arget="#m3"
        pred=friday" determinacy="det"/>
      <participation event="eQ1" participant="xQ3"
        semRole="time" distr="individual"
      '  evScope="narrow" />
 </quantml>
 <idl xml:id="crIL" target="#m0">
      <idLink xml:id="i1" arg1="#eQ1" arg2="#eT"1/>
      <idLink xml:id="i2" arg1="#xQ2" arg2="#tT1"/>
 </idl>
</linkedRep>
```

ABSTRACT SYNTAX:
Using the schematic notation of (3), instantiated as above:

QuantML

$\mathsf{A}_Q = dF_Q(crQ) =$
$= \langle \epsilon_{Qe}, \langle \epsilon_{xQ1}, \epsilon_{xQ2} \rangle, \langle pL_{Q1}, pL_{Q2} \rangle, \langle scL_1 \rangle \rangle$
$\epsilon_{Qe} = dF_Q(IdEL(crQ, e_Q)) = \langle$*evt*, $\langle$call, past$\rangle\rangle$
$\epsilon_{xQ1} = dF_Q(IdEL(crQ, xQ1))$
$\langle$*ent*, $\langle$John, determinate, count, 1$\rangle\rangle$
$\epsilon_{xQ2} = dF_Q(IdEL(crQ, xQ2))$
$\langle$*ent*, $\langle$midnight, determinate, count, 1$\rangle\rangle$
$pL_{Q1} = \langle$*pLink*, $\langle \epsilon_{Qe}, \epsilon_{xQ1}$, agent, individual$\rangle\rangle$
$pL_{Q2} = \langle$*pLink*, $\langle \epsilon_{Qe}, \epsilon_{Qxt}$, time, individual$\rangle\rangle$,
$scL_{Q1} = \langle$*scope*, $\langle pL_{Q1}, pL_{Q2}$,wider$\rangle\rangle$

ISO-TimeML

$\mathsf{A}_T = dF_T(crT) = \langle \epsilon_{Te}, \langle \epsilon_t \rangle, \langle tL_1 \rangle \ \langle\rangle\rangle$
$\epsilon_{Te} = dF_T(IdEL(crT, e_t))$
$= \langle$*evt*, $\langle$call, occurrence, transition, past$\rangle\rangle$
$\epsilon_{Tt} = dF_T(IdEL(crT, tT1) = \langle$*instant,* $\langle$T00:00$\rangle\rangle$
$tL_{T1} = dF_T(TL(crT) = \langle$*tLink*, $\langle \epsilon_{Te}, \epsilon_{Tt}$, included$\rangle\rangle$

Interlinking:

$\mathsf{A}_{IL} = dF_{IL}(crIL) =$
$= \langle dF_{IL}(\mathsf{IdEl}(crIL), i1), dF_{IL}(\mathsf{IdEl}(crIL, i2))\rangle$
$= \langle\langle \epsilon_{Qe}, \epsilon_{Te} \rangle, \langle \epsilon_{xQ2}, \epsilon_{Tt} \rangle\rangle$crIL

Interlinked annotation structure:

$\mathsf{A}_{QT} = dF_{QT}(crQ + crT + crIL)$
$\langle \epsilon_e, \epsilon_x, pL, scL \rangle$, where
$\epsilon_e = dF_{IL}(\mathsf{IdEl}(crIL), i1) = \langle \epsilon_{Qe}, \epsilon_{Te} \rangle$
$\epsilon_x = \langle dF_{QT}(\epsilon_{Qx1}), dF_{QT}(\epsilon_{xQ2}), dF_{QT}(\epsilon_{Tt}) \rangle$
$= \langle \epsilon_{Qx1}, \langle \epsilon_{xQ2}, \epsilon_{T1} \rangle\rangle$
$=_D \langle \epsilon_1, \epsilon_2 \rangle$
$pL = \{pL_1, pL_2\}$
$pL_1 = pL_{Q1}$
$pL_2 = \mathsf{PLink}(\langle pL_{Q2}, tL_{T1} \rangle) =$
$= \langle \epsilon_e, \epsilon_2, \langle \mathsf{SRole}(pL_{Q2}), \mathsf{SRole}(tL_{T1} \rangle,$
$\mathsf{Params}(pL_{Q2})\rangle$
$= \langle \epsilon_e, \epsilon_2, \langle$time, simultaneous$\rangle$,
$\langle$individual, narrow, non-exh, positive$\rangle\rangle$
$scL = \{dF_{QT}(scL_{Q1)}\}$

SEMANTICS:

$I_{QT}(\mathsf{A}_{QT}) = I_{QT}(scL_1)$
$= I_{QT}(pL_1) \cup^* (I_{QT}(pL_2)$
$I_{QT}(pL_1) = I_Q(pL_{Q1}) = [X| \ |X| = 1, x \in X \leftrightarrow$ $\mathsf{john}_0(x), x \in X \rightarrow$
[E | e ∈ E → [call(e), agent(e,t)]]
$I_{QT}(pL_2) = I_{QT}(\langle \epsilon_e, \epsilon_2,$
$\langle$time, simultaneous$\rangle$, individual, narrow,
$\langle$inon-exh, positive$\rangle$)=
$= I_{QT}(\langle\langle \epsilon_{Qe}, \epsilon_{Te} \rangle, \langle \epsilon_{xQ2}, \epsilon_{Tt1} \rangle, \langle$time, simultaneous$\rangle$, $\langle$individual, narrow, non-exh, positive$\rangle$)$\rangle$
$= \cup^+(I_Q(\epsilon_{Qe}) \cup I_T(\epsilon_{Te}), I_Q(\epsilon_{xQ2}) \cup I_T(\epsilon_{Tt1}),$
$\lambda x, y.\ \mathsf{time}(e, y) \wedge \mathsf{simultaneous}(x, y)$
$= \cup^+([E|e \in E \rightarrow \mathsf{call}(e), \mathsf{past}(e), \mathsf{occurrence}(e), \mathsf{transition}(e)],$
$[T||T| = 1, t \in T \leftrightarrow \mathsf{midnight}_0, t \in T \rightarrow \mathsf{clocktime}(t) = 00{:}00],$
$\lambda x, y.\ \mathsf{time}(e, y) \wedge \mathsf{simultaneous}(x, y))$
$= [T||T| = 1, t \in T \leftrightarrow \mathsf{midnight}_0, t \in T \rightarrow \mathsf{clocktime}(t) = 00{:}00], [E|e \in E \rightarrow \mathsf{call}(e), \mathsf{past}(e), \mathsf{occurrence}(e), \mathsf{transition}(e)),$
$\mathsf{time}(e, t), \mathsf{simultaneours}(e, t)]]$

The interpretation of the integrated annotation is thus:

$I_{QT}(\mathsf{A}_{QT}) = I_{QT}(pL_1) \cup^{**} (I_{QT}(pL_2)$
$= [X| \ |X| = 1, x \in X \leftrightarrow \mathsf{john}_0(x),$
$x \in X \rightarrow [T||T| = 1, t \in T \leftrightarrow \mathsf{midnight}_0(x),$
$t \in T \rightarrow \mathsf{clocktime}(t) = 00{:}00),$
$[E|e \in E \rightarrow \mathsf{call}(e), \mathsf{past}(e), \mathsf{occurrence}(e),$
$\mathsf{transition}(e)), \mathsf{agent(e,x)}, \mathsf{time}(e, t),$
$\mathsf{simultaneous}(e, t)]]$