# Managing imperfect temporal metadata in the Catalog services of Spatial Data Infrastructures compliant with INSPIRE

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***Abstract****—In this paper we analyze the limitations of current recommendations of the INSPIRE (Infrastructure for Spatial Information in Europe) Directive as far as the temporal metadata definition for discovery purposes, and propose its extension so as to allow the representation and management of imperfect spatio-temporal metadata. We propose to extend the metadata in order to cope with the requirements of both metadata producers, who often are unable to specify precise values, and users who submit queries to catalog services for discovering interesting data, who may express soft selection conditions on metadata values. The proposal is illustrated and explained through an example taken from an active Spatial Data Infrastructure (SDI).*

***Keywords***— Geo-data, INSPIRE, metadata, Spatial Data Infrastructure, spatio-temporal imperfection.

## 1 Introduction

Infrastructures are complex systems in which a network of interconnected but autonomous components is used for the exchange and mobility of goods, persons, information. Their successful exploitation requires technologies, policies, investments in money and personnel, common standards and harmonised rules. Typical examples of infrastructures which are critical for society are transportation and water supply. In Information Technology, the term infrastructure could be related to communication channels through which information can be located, exchanged, accessed, and possibly elaborated. Since the last decade of the past Century, creation of infrastructures for spatial information emerged as an issue in some countries in order to prevent wasting of money in geo-data multiple creation, to favour their shares at multiple levels in the society, and to support decision making in various fields, such as the environment [1]. In 2007, the INSPIRE Directive of the European Parliament and of the Council entered into force [2] to trigger the creation of a European Spatial Data Infrastructure (ESDI) that delivers to the users integrated spatial information services*. These services should allow users to discover and possibly access spatial or geographical information from a wide range of sources, from the local to the global level, in an inter-operable way for a variety of uses. Discovery is performed through services that should follow INSPIRE standards and can be implemented through some products (either proprietary or not) that declare their compliance. Users' conditions, expressed through discovery service clients, are matched against archived metadata, describing associated geo-data, in order to give an answer to the above conditions. The matching result is a list (sometimes empty) of records of metadata satisfying the match. Discovery services currently provide an exact matching: users cannot express flexible selection conditions, enabling partial matching mechanisms between the ideal metadata and the archived metadata.

On the metadata side, their creation is usually in charge of data/services providers: metadata fields, their meaning, and their types/ranges of values are defined in INSPIRE through recommendation documents aimed at easing discovery [3], [4]. With respect to the temporal characterisation, current recommendations for metadata specification are inadequate for metadata providers: some needed fields are missing; the semantics of the recommended fields is ambiguous; they do not consider nor manage representation of uncertain or vague information due to incomplete knowledge.

In this paper we take into account this last drawback and propose to let imperfect temporal values be used by both metadata providers in describing the temporal validity of the geodata, and SDI users in expressing discovery conditions. Moreover we suggest mechanisms to introduce partial matching in discovery services.

## 2 Metadata extension proposal within SDI architecture of INSPIRE

### *2.1 SDI Architecture*

An overview of the current understanding of the technical architecture of INSPIRE is depicted in figure 1; it has been adopted by the ESDI [5].

Discovery services are the element aimed at discovering information of interest to the users. They are connected to metadata catalogues, necessary due to the intrinsically distributed nature of an SDI, where information repositories

* Following the Directive, components of European SDIs include: metadata, spatial data themes (as described in Annexes I, II, III of the Directive), spatial data services; network services and technologies; agreements on data and service sharing, access and use; coordination and monitoring mechanisms, processes and procedures.

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are owned and maintained on the Web servers of different organisations. Services managing catalogues could have the twofold function of archives of metadata, which describe either geo-data or geo-services available in the SDI, and of discovery tools, able to match users' search conditions with archived metadata. Catalogues services should be fitted to let users express selection conditions that specify "what" is of interest through content keywords (e.g., landslides), "why" they are searched (e.g., to detect recurrence of landslides), "where" the interesting features should be located (e.g., in a bounding box surrounding the Alps), and "when" these features should have been observed (e.g., the date/s of the observations).

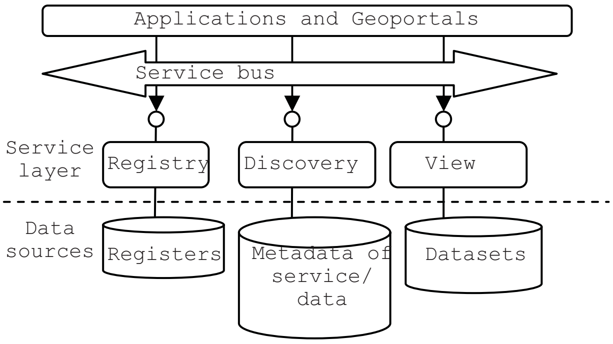


Figure 1: INSPIRE technical architecture overview; discovery service and metadata

*2.2 Temporal metadata in INSPIRE SDIs*

In order to ensure that the SDIs participating in the ESDI are compatible and usable in a trans-boundary, multicultural context such as Europe, the INSPIRE Directive requires that common Implementing Rules (IR) are adopted in a number of specific areas, in particular in metadata definition. The INSPIRE Metadata IR Version 3 of 26th October 2007 [4] defines four elements of temporal information, i.e.:

1. *Temporal extent*, the time period covered by the content of the resource
2. *Date of publication* of the resource
3. *Date of last revision* of the resource if the resource has been revised
4. *Date of creation* of the resource if it has not been revised

Only the first element (Temporal reference-5.1 Temporal extension) can be used to describe a temporal aspect of the content of geo-data itself, since the following three elements are referred to geo-data life cycle as a document. Nevertheless it plays an unavoidable role in numerous use cases, such as searching for events occurring in a particular period of time, looking for multiple observations of the same geographic area, evaluating if data can be used for a particular process, etc.

A specific study has been commissioned in order to improve temporal metadata specification [6]. It introduces some recommendations that rise attention to the role of 'Temporal extent' element; specifies the type and format of time values to be adopted either in expressing dates or time periods; suggests how to preserve precision in exchange or conversion processes.

*2.3 Proposal of extension of temporal metadata*

In our opinion and based on the experience as partners in the European Project IDE-Univers (http://www.ideunivers.eu), some further extensions should be adopted to improve temporal characterisation of geo-data in an SDI. In fact, the current specification of INSPIRE does not allow to specify the time relative to the occurrence of the event that is observed in one, several or a series of spatial data. Furthermore, current formats do not allow to specify imperfect values for metadata, both temporal, spatial, and thematic, which are the only kind of values that metadata producers can sometime provide, given that they often do not have enough information to specify precise values.

For example, if one has to create the metadata of a series of remote sensing images of a landslide that occurred in 1986 taken in distinct periods during its monitoring after its occurrence, the current specification just allows to indicate the time of the observations and not the time of the event, i.e. of the landslide occurrence. Nevertheless, this can be a very important information in an SDI context, because one can be interested in comparing the status of a landslide in different periods of time in the same place, as they appear in distinct images. One then, must be sure that the compared images refer to the same event, and not to distinct ones.

Moreover, in real situations, it often happens that the date or time of occurrence of an event is ill-known. This is due to several reasons: either because the event was not observed during its occurrence, and thus it can only be guessed by experts, or because it occurred long time ago so that its date can be deduced only imprecisely by the dating methods available (e.g., this is the case or archeological sites, geologic and paleontological findings).

In summary we propose:

- To introduce the possibility to include in metadata one or more events/processes/phenomena of reference for the geo-data: a satellite image can be an observation of fires in a region; a set of meteo records are measures of a rainfall; some thematic maps can be subsequent representations of urban growth, etc. A temporal extent element should be defined also for the reference event(s), of course.
- To allow the definition in metadata of soft temporal values in the temporal extent element of both geodata and related event(s); soft values should be allowed in the expression of single time points (by ex. the landslide occurred in the night of 15th December, 2005), of time intervals (by ex. snow precipitation of three days starting from 14th December 2008), and of subsequent either periodic or aperiodic dates/intervals (ex. fires occurring each Summer).

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## 3 Basic framework of the proposal

### 3.1 Extension of temporal metadata in INSPIRE

Notwithstanding we are aware that further extensions are possible, in this contribution we propose to include the following temporal metadata:

Instant in which the observation/event occurred:

- Date, time (e.g. the landslide occurred the 11-07-2008 at 8:00:00)

Period of validity, or duration of an observation/event:

- period (interval of dates, times) (e.g. the duration of a fire was from 11-07-2008 to 13-07-2008)

Sequence of instances of occurrences/events:

- multiple instants of time or dates (e.g. the dates of the distinct fires were 11-07-2008 , and 12-07-2008)

Sequence of periods of validity or duration of occurrences/events:

- multiple periods or durations (e.g. the times of the distinct fires were from 11-07-2008 to 13-07-2008 and from 20-08-2008 to 23-08-2008)

We also extend the time metadata format so as to allow the specification of ill-known instants, intervals and time series by means of fuzzy instant, fuzzy intervals and fuzzy time series associated with any kind of observation/event.

First of all we describe a formal framework in which all these fuzzy temporal indications are modeled, adopting the proposal of [7]. In order to express such fuzzy temporal indications into an eXtended Markup Language (XML)-type language, that is required for INSPIRE metadata, we adopt TimeML specification language [8].

The use of TimeML is motivated by the fact that it is a textual meta language, thus easy to read and to index by common Information Retrieval techniques, that can be employed in a catalog service context in order to represent the metadata contents for a successive search and discovery. It is enough flexible to allow the annotation (description) of the kind of event/observation and its temporal information, possibly imprecise and vague.

In the following subsections, let us first describe the representation within fuzzy set theory and possibility theory of time expressions, then introduce TimeML and specifically the tags we adopt, and finally, the partial matching mechanism we propose.

### 3.2 Modeling flexible time indications within the fuzzy set and possibility framework

The representation of temporal information requires the choice of a numeric scale to describe the order of events and phenomena; this scale is defined by an origin (time t=0) and a time unit, so that events occurred before t=0 have a negative time values and those occurred after have positive values. The choice of the time unit depends on the cycles of an observed periodic phenomenon, such as the movement of the sun. Nevertheless almost every time scale shares the basic unit *second*, and other units with lower granularity such as *minute*, *hour* and *day*. Besides these units of time, there are other natural language time indications such as *week*, *month*, *season*, *year*, *century* that are artificial notions, defined within a calendar such as the Julian and Gregorian ones. Other notions of time, related to human experience such as *now*, *soon*, *recent*, *often*, *end of the year*, are approximate time indications.

Several time models have been proposed [9], their common limitation is that they deal with crisp time indications.

A flexible framework has been defined within fuzzy set and possibility theory to express approximate hierarchical time indications close to natural language at distinct level of granularity [7]. It takes inspiration from the time hierarchy proposed in [10] and the time granularity defined as a mapping from the set of positive integers to the absolute time proposed in [11], and builds up a multi-granular hierarchical time structure in which also vague and imprecise time granules can be defined.

We assume this approach at the basis of our proposal. In this way it is possible to express temporal indications in several time units with distinct granularities, the less refined ones obtained by grouping units of the higher level granularity.

A *basic domain* $G_0$, consists of granules of time points below which the elements are not discernable. For example if $G_0$ is *hour* we cannot discern the *minutes* within an hour. Notice that, a granule of a domain G' (e.g. G'=*week*) that is not the basic domain $G_0$ (e.g. $G_0$=*hour*) can be defined by recursively grouping granules of its parent domains G=*day* and $G_0$ in the hierarchy. For example G'=*week*=7**day* =7*24*$G_0$=168*hours*.

The set of temporal specifications that we adopt are listed here following.

A *time point* indication is defined as a pair [t, G] in which t is an ordinal indicating the position with respect to the time origin on a domain G of granules. An example is: [t=2, *day*] that indicates the second day from the time origin; a fuzzy example is [t={0.8/3, 1./4, 0.7/5}, *day*] that means around the fourth day after the time origin.

A duration in time, i.e. a *time span*, is a pair [Δt, G] and can be denoted by either a set or a range of time points. A fuzzy time span example is [Δt ={0.8/3, 1./4, 0.7/5}, *year*] that means a duration of about 4 years.

A temporal distance from the origin, i.e. a *time distance*, is defined as a pair [d, G] in which d is a positive or negative value, indicating the distance in time granules on G from the origin. In this case [d=2, *day*] means two days after the origin. As t, also d can be a fuzzy set indicating a fuzzy time distance.

A *time interval* is a triple [t, Δd, G]; in a crisp case [t=1991, Δd=3, *year*] means 3 years from 1991.

A *composite span* is a union of spans $\cup[\Delta t_i, G_i]$, not necessarily adjacent and on the same basic domain G.

An *aperiodic time element* is a union of time intervals $\cup[t_i, \Delta d_i, G_i]$. The crisp example [t=1-11-2008, Δd=28, *day*] ∪ [t=30-11-2008, Δd=31, *day*] means 28 days from 1-11-2008 and 31 days from 30-11-2008.

A *periodic time element* is a union of a time interval and a time distance: $\cup[t_i, \Delta d_i, G_i]$, $[d_k, G_k]$. By example ∪[t=1-8-2000, Δd=31, *day*], [d=1, *year*] means every August from

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year 2000. An example of vague periodic time element is $\cup$ [t=1-2000, $\Delta$d={0.2/1, 0.8/2, 1./3, 0,8/4}, *week*], [d=1, *year*] that means around the third week of every January from year 2000.

Since in the context of metadata compilation we may have time series that are related to finite repetitions of observations or events a *finite periodic time element* is defined as a composition of a periodic time element and a time point: $\cup[t_i, \Delta d_i, G_i], [d_k, G_k], [t, G]$ in which the time point t specifies the end of the repetition. An example of finite periodic time element is "*every autumn from 2000 to 2005*" that is formally expressed as: $\cup$[22-09-2000, 90, *day*], [1, *year*], [21-12-2005, *day*].

### 3.3 TimeML specification language for flexible time indications

TimeML is a markup language of the XML family for describing events, signals and temporal expressions into a text written in natural language. It is designed to address four situations:

1. Time stamping of events (identifying an event in time, instant or interval of validity).
2. Ordering events with respect to one another (relative ordering).
3. Reasoning with contextually underspecified temporal expressions (temporal functions such as 'last week' and 'two weeks before').
4. Reasoning about the persistence of events (how long does an event or the outcome of an event lasts).

The tags in TimeML[†] that we adopt to extend the INSPIRE metadata and that we model within the fuzzy framework previously described, are listed and illustrated in Table 1.

Table 1: TimeML tags adopted in this proposal

| |
|---|
| EVENT |
| Tag used to annotate the semantics of the event described. Syntactically, EVENT can be a verb (such as "raining"), but also a nominal, such as "fire" |
| MAKEINSTANCE |
| It indicates different instances (observations) of a given event. Different instances can have different attribute values, and every EVENT introduces at least one corresponding MAKEINSTANCE |
| TIMEX3 |
| This tag is central to our objectives since it is primarily used to mark up explicit temporal expressions, such as times, dates, durations, etc. TIMEX3 allows marking up the following types of temporal indications specified by the attribute `type`:<br>*Durations* such as "four weeks", "half a year";<br>*Calendar dates* (points in time equal or bigger than a day) both precise such as "13 August 2007" and imprecise or vague such as "few days ago", "end of July", "at the beginning of summer";<br>*Times of day* (smaller than a day) both precise such as "at 9.50.00 a.m." and imprecise or vague such as "before noon";<br>*Sets* (Recurring time expressions) such as "every month", "twice a week"<br>The `value` attribute can assume XML datatypes based on the 2002 TIDES guideline, which extends the ISO 8601 standard for representing dates, times, and durations. E.g. "twelve weeks" becomes "P12W" and "21 February 2008 at 8.30.00 a.m." becomes "2008-2-21T8:30:00"<br>The `mod` attribute allows specifying temporal modifiers that cannot be expressed either within `value` proper, or via links or temporal functions, such as "before", "after", "equal or less", "end". |
| TLINK |
| one of the TimeML link tags which encodes the relations that exist between two temporal elements (e.g., `BEGINS, HOLDS, INCLUDES, AFTER)` |

[†] TimeML vers. 1.2.1 <http://www.timeml.org>

For example the expression "*every autumn from 2000 to 2005*" is formulated in TimeML as follows:

```
<TIMEX3 tid="t10" type="SET" value="R6/2000-09-22/P1Y0M0D">
every autumn from 2000 to 2005
</TIMEX3>
```

Finally, in TimeML it is possible to mark confidence values to be assigned to any tag and to any attribute of any tag. The confidence value associated with the `value` attribute of TIMEX3 expresses the uncertainty that the metadata provider has in assigning the temporal indication to an event or observation. For example, we can add the confidence annotation to TIMEX3 so as to specify the uncertain date of an observation that might have occurred the first or second of January 2000 as follows:

```
<TIMEX3 tid="t1" type="DATE" value="2000-01-01">
On January 1st, 2000
</TIMEX3>
<CONFIDENCE tagType="TIMEX3" tagID="t1"
confidenceValue="1."/>

<TIMEX3 tid="t2" type="DATE" value="2000-01-02">
On January 2nd, 2000
</TIMEX3>
<CONFIDENCE tagType="TIMEX3" tagID="t2"
confidenceValue="0.80"/>
```

## 4 Management of the proposed temporal metadata extension

The frameworks and assumptions of section 3 can be used to define the temporal fields associated with events and observations in the metadata of a SDI catalogue.

The metadata provider defines the time indications of events and observations by means of a metadata editor. We propose an example of the metadata of two thematic maps representing subsequent observations from satellite of the same event, i.e. the melting of the Lys Glacier (a glacier of the Italian Alps), during Summer 2007. In this example, the temporal indications of the occurrence of the observations are known precisely. Following the extension we propose, in the metadata of the first map we could have fields such as:

<u>Metadata 1</u>

…
Event="Lys Glacier melting"
Occurrence="observation of Lys Glacier melting"
    Time Position of Occurrence="1.7.2007"
…

In the metadata of the second map we could have:

<u>Metadata 2</u>

…
Event="Lys Glacier melting"
Occurrence="observation of Lys Glacier melting"
    Time Position of Occurrence="3.9.2007"
…

Metadata are translated into TimeML sentences like in Table 2.

To allow partial matching with respect to flexible selection conditions specified by a user a parser translates the external TimeML definitions of temporal metadata into their internal fuzzy set representation $\mu_t$. We can have fuzzy sets defined on distinct domains (G). The hierarchy of basic temporal concepts defining the temporal domains with distinct granularity, is represented by a graph that contains in each edge connecting node i to node j a mapping function $F_{i,j}$ that allows converting the current granule of the i-th node in terms of aggregation of granules of the j-th node (see Fig 2 which is a simplification to illustrate how the concept works).

This function $F_{i,j}$:G'→G, with G⊂G', and i,j identifiers of the i-th and j-th nodes, with i-th node defined on domain G' and j-th defined on G, associates a granule g'∈G'→$F_{i,j}$(g')∈G, where $F_{i,j}$(g') is a fuzzy set of granules on G. A temporal indication *t*, defined on G' (e.g., 2002 year) can be converted on another domain G (e.g., day) by repeatedly applying the mapping functions $F_{i,j}$ associated to the edges on the path from node G*'* to node G as proposed in [12].

Table 2: TimeML example

```
Lys Glacier
<EVENT eid="e10" class="OCCURRENCE">
is melting
</EVENT>
<MAKEINSTANCE eiid="ei1" eventID="e10"
pos="VERB" tense="PRESENT" aspect="PROGRESSIVE"
/>
<TIMEX3 tid="t2" type="DATE" value="2007-07-01">
On July 1st, 2007
</TIMEX3>
<TLINK eventInstanceID="ei1" relatedToTime="t2"
relType="DURING"/>
<MAKEINSTANCE eiid="ei2" eventID="e10"
pos="VERB" tense="PRESENT" aspect="PROGRESSIVE"
/>
<TIMEX3 tid="t3" type="DATE" value="2007-09-03">
On September 3rd, 2007
</TIMEX3>
<TLINK eventInstanceID="ei2" relatedToTime="t3"
relType="DURING"/>
...
```

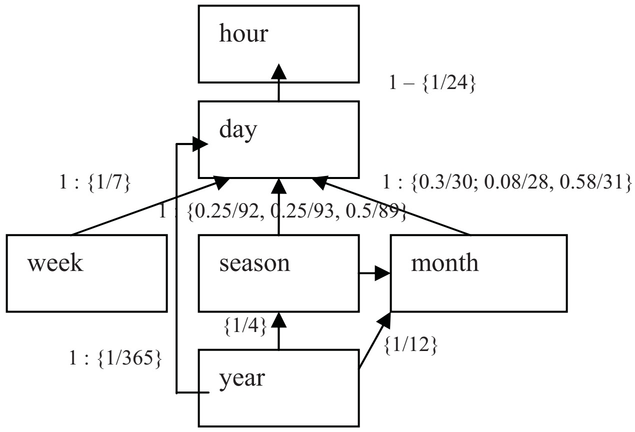


Figure 2: Simplified example of temporal graph: on each edge the fuzzy set defining the conversion function F of granules.

However, since there can be more than a single path $P_1$, ..$P_k$, connecting two nodes (e.g., $P_1$=*year*, *season*, *day* and $P_2$= *year, month, day*), multiple definitions of *t* on the domain G can be obtained $t_{P1}$, .. $t_{Pk}$ In order to reconcile these definitions we choose the one obtained by considering the shortest path connecting the two nodes. If there exists more than one of such short paths with same length we generate the maximum bound of their definitions:

$$t_{P1 \oplus P2 \oplus Pk}(g) = \max(t_{P1}(g) .. t_{Pk}(g))$$

The reason for this choice is that the maximum bound comprehends all possible definitions of the temporal indication on the domain G.

For example, the sentences in Table 2 correspond to the two *time points* [$t_1$=1-7-2007, *day*], and [$t_2$=3-9-2007, *day*], with crisp pointwise membership functions.

On the other side, the user specifies her/his temporal soft selection conditions Q within a catalog service interface. They can be expressed by specifying soft constraints, i.e. with a desired membership function $\mu_Q$, defined on a time line with a given granularity, chosen among one of the available in the temporal hierarchy (e.g. see fig. 3). An example of user selection condition for the Lys Glacier melting case reported in table 2 could be: *"Search for occurrences of glacier melting observations, occurring close to late Summer 2007".*

Users' temporal query specifications are converted into the internal fuzzy set representation and, if necessary, transformed into the granularity of the data they have to be matched. The soft constraint of the example corresponds to a vague *time interval* with trapezoidal membership function $\mu_Q$ such as [t=15-6-2007, Δd={ 1-8-2007, 15-8-07, 23-9-2007, 10-10-2007}, *day*].

The internal fuzzy representation of the temporal metadata $\mu_t$ are then matched with the fuzzy representations of the soft query constraint $\mu_Q$ by applying a representation-based matching function as proposed in [13][14].

In this representation-based framework, both the metadata values $\mu_t$, possibly uncertain, and the soft query condition $\mu_Q$ are interpreted as soft constraints and one can match

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them to obtain a degree of satisfaction $RSV(t,Q)\in[0,1]$, by computing either a measure of similarity [14] or a fuzzy inclusion measure [13] between the two fuzzy sets $\mu_Q$ and $\mu_t$.

In the specific case of matching temporal constraints, it makes sense to allow the choice of both matching functions. One could be interested in selecting observations of an event taken in a date *close* to another date. This corresponds to select the similarity matching function [14]:

$$RSV(t,Q)=Similarity(\mu_t,\mu_q)=\frac{\sum_{i\in G} min(\mu_t(i),\mu_Q(i))}{\sum_{i\in G} max(\mu_t(i),\mu_Q(i))}$$

in which $\mu_t(i)$ and $\mu_Q(i)$ are the membership degrees of a time point i in a fuzzy metadata value t and in the query constraint Q.

Another case is when one wants to select observations that occurred *within* a period. This corresponds to select a matching function defined as a fuzzy inclusion [13]:

$$RSV(t,Q)=Inclusion(\mu_t,\mu_q)=\frac{\sum_{i\in G} min(\mu_t(i),\mu_Q(i))}{\sum_{i\in G}(\mu_t(i))}$$

Other matching functions could be defined corresponding with other temporal relations such as "*close before*" "*close after*" "*recent*" and so on.

The retrieved metadata can be ranked in decreasing order on the basis of *RSV* values, thus avoiding empty answers and suggesting an access order to the referred geo-data. In the example, both metadata are retrieved: Metadata 2 has a *RSV* score "1" being situated in late Summer, while Metadata 1 is also retrieved since it partially satisfies the query condition "*close*", thus meaning that it is associated to an observation of glacier melting that is in proximity of the limits of the temporal range 'late Summer'.

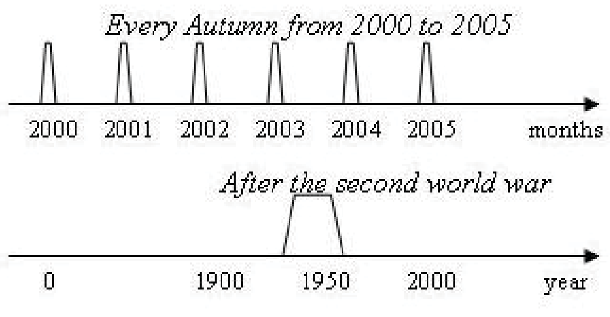


Figure 3: Examples of two soft temporal constraints defined on two timelines with distinct granularity (months and years, respectively). The constraint "*every Autumn from 2000 to 2005*" is defined as a fuzzy finite periodic time element, while "*after the second world war"* as a fuzzy time interval.

## 5 Conclusions

Spatial Data Infrastructures are becoming a common practice for discovering and accessing distributed heterogeneous geo-data. Nevertheless, the catalogue services on which SDIs are based are still founded on old database paradigms, that do not allow partial matching mechanisms, nor the representation and management of ill-defined metadata.

The present paper represents a first step in the proposal of a fuzzy framework to model catalogue services functionalities to manage ill-defined metadata and flexible queries. Specifically, we proposed a solution to express, represent, and manage temporal metadata, possibly imperfect, in a flexible way even if the revising policy within INSPIRE is long and needs to overcome several reviewing steps.

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