# Modeling Temporal Uncertainty of Events: a Descriptive Perspective

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## 1. Introduction

Many geographical or social events are associated with particular spatio-temporal extents. The concept of spatio-temporal setting has been introduced to demonstrate how events are situated in space and time (Worboys and Hornsby 2004). In practice, the extent of an event is often textually described. A typical example is "the 2008 Sichuan earthquake occurred at 14:28 on May 12 2008 in Sichuan, with the epicenter of 31.021°N 103.367°E". This description is rather precise. A relatively rough expression may be "the 2008 Sichuan earthquake occurred on May 12 2008 in China". Obviously, this description introduces uncertainty to the event being described. In many applications, we should model and estimate the spatio-temporal uncertainty of events due to descriptions. For example, in the research of time geography, which focuses on the temporal factor in human spatial activities, most source data are collected from surveying questionnaires, where activities are textually described and thus often uncertain. Hence, to model descriptive events and the associated uncertainty will contribute to more exact representations of human behaviors in time geography.

## 2. Uncertain Time Descriptions

In practice, we can identify two kinds of descriptive temporal objects (DTO): time instants and time intervals. Both instants and intervals could be represented either quantitatively or qualitatively. A quantitative temporal description is a combination of numbers and numeric units, while qualitative time concepts are characterized by natural or human attributes. Additionally, DTOs can be combined with temporal relationships, and both topological and metric relationships are widely used in time descriptions.

In the research, we adopt fuzzy sets to represent a DTO textually described (Schockaert and De Cock 2008). Obviously, if the DTO is a crisp closed interval $[p_1,p_2]$, then the membership degrees for all points inside the interval are 1. Note that the beginning and ending of a crisp interval may be open (Figure 1a). However, a DTO may be vague due to descriptions. The vagueness may arise from the adopted vague periods (e.g. "morning"), vague events (e.g. "the Renaissance"), and vague relationships (e.g. "around 8:00 am"). Hence, for a particular instant, the membership degree may be a real number between 0 and 1 (Figure 1b). We use crisp endpoints and vague endpoints for the DTO depicted in Figures 1a and 1b. In many relationship-based descriptions, the endpoints are not explicitly specified. Without considering contextual information, such a time object (TO) has one infinite endpoint (Figure 1c).

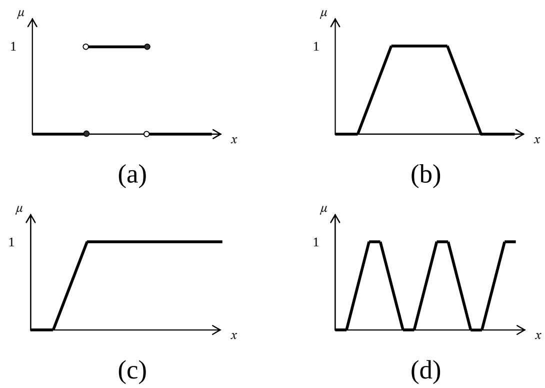



Figure 1. Different cases of uncertain DTO represented by fuzzy sets.

A DTO may also be uncertainty due to imprecision besides vagueness. Let us take "World War II, 1937-1945" as an example. The actual beginning and ending are uniformly distributed in 1937 and 1945, respectively. Hence, the membership degrees of the temporal points in years from 1938 to 1944 are all 1. For points in 1937 and 1945, we can use integral operations to compute the membership degrees, by summarizing all possible circumstances when World War II starts before (or ends after) the target point. Finally, a trapezoid MF can be obtained (Figure 1b).

Following above discussions, we can establish a unified representation for DTOs as follows. A fuzzy temporal object $I$ is characterized by a membership function $\mu_I(x)$. For each $x \in R$, the value $\mu_I(x)$ represents the membership degree that $x$ is in $I$. The support of $I$ is $supp(I) = \{x : \mu_I(x) > 0\}$ .

## 3. Uncertain Events

In an event description, the temporal settings (TS) are specified mainly based on two kinds of constraints. One is the relationship between the TS and the DTO, the other is the length constraints on the target event. For example, in the description "I had a two-hour meeting yesterday", the two kinds of constraints are both used. In practice, there are three categories of length constraints in event descriptions: 1) quantitative constraints (e.g., "a two-hour meeting"), 2) qualitative constraints (e.g., "a short meeting"), and 3) combined constraints, which combines distinctions like "about" and "around" with quantitative constraints. A typical example is "the meeting duration was about two hours". In order to model the uncertainty of events, the above constraints should be taken into account.

Considering the relationship between the TS $T$ of an event $E$ and the DTO $R$ described by an assertion $X$, an ideal case is that $R$ is crisp and equals $T$ (Figure 2g). Unfortunately, an exact description rarely occurs in practice. Figs. 2 a-f depict six common relationships between $T$ and $R$. $E$ is punctual and $T$ is modeled by an instant for each case in Figs. 2a-c, while $E$ is durative and $T$ is an interval in Figs. 2d-f. Note that a DTO may have infinite endpoint (Figs. 2a,c,d,f), such as "before the World War II". Although only one endpoint is specified, the other endpoint may be inferred according to the context. Therefore, in this research, the support of $R$ is modeled to be an interval or a set of intervals when considering periodic expressions. For simplicity, we mainly investigate single interval cases and assume intervals are closed.

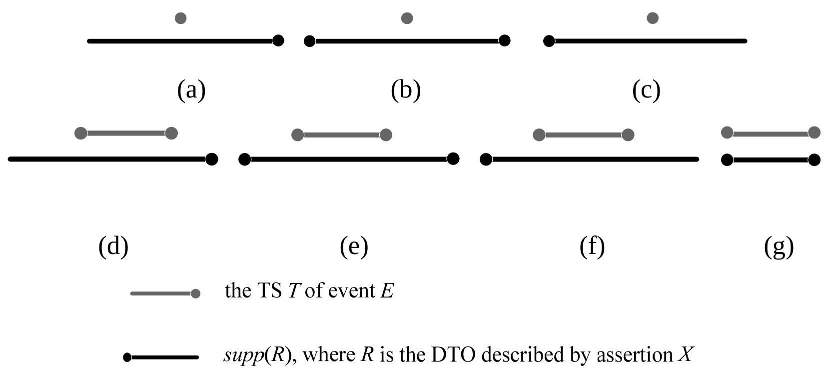



Figure 2. Seven cases of the relationship between $T$ and $R$.

Though the boundary of an event is crisp, uncertainty may be introduced when we describe it. First, the DTO associated with a time description is potential to be uncertain. Second, a given temporal assertion may represent only an approximate range of the target event. For instance, the description "arrived at Beijing between 6:00 to 6:10" indicates a possible arriving time within the interval "6:00-6:10". Without considering other conditions, the actual time point of "arriving" is uniformly distributed in the interval.

Suppose the TS $T$ of an event is inherently crisp. The DTO for describing $T$ is represented by a vague interval $R$ with a membership function $\mu_R(x)$, where $x \in \mathrm{supp}(R)$. The uncertainty of DTO can be modeled from the following two aspects. First, if $T$ is an instant, then we can use a probability density function (PDF) $p_{PT}(x)$ for the descriptive uncertainty of $T$. Second, if $T$ is an interval, we introduce two-dimensional PDF $p_{IT}(u,v)$, and a probability function $P_T(x)$ modeling the probability that $x$ is inside $T$, to represent the uncertainty of $T$. We name $P_T(x)$ the temporal covering probability function of the event.

In this research, we investigate the uncertainty of events considering the following four situations:

(1) The reference DTOs are crisp or vague;

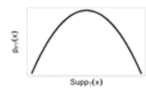
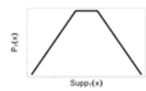
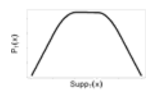
(2) The events are punctual or durative;

(3) The durative events have or have not length constraints;

(4) the length constraints are certain or uncertain.

Table 1 summarizes all results by listing several example event descriptions and their conceptual $P_T$(x) (or $p_{PT}(x)$ for punctual events). Note that in column "Event Type", *P* stands for punctual events while *D* stands for durative events.

Table 1. Example descriptions and their conceptual $P_T$(x) (or $p_{PT}(x)$)

| Examples | Event type | $P_T(x)$ (or $p_{PT}(x)$) |
|---|---|---|
| left the city on Monday | *P* |  |
| left home in the afternoon[1] | *P* |  |
| had an one-hour class on Monday | *D* |  |
| had a long class on Monday | *D* |  |
| had a class on Monday | *D* |  |
| had a class in the afternoon | *D* |  |
| had an one-hour class in the afternoon | *D* |  |
| had a long class in the afternoon | *D* |  |

## 4. Conclusions

The temporal uncertainty of events mostly comes from uncertain time descriptions. For a description "a meeting in this morning", the associated uncertainty includes two aspects. First, "this morning" indicates a temporal object with vague boundary. In this research, we use fuzzy sets to model descriptive temporal objects. Second, the actual occurrence time of the event (i.e. "meeting") is generally inside the DTO, which is described by "this morning", with particular probability distribution. To quantitatively model the second aspect of event uncertainty, a probabilistic method can be proposed to represent its temporal probability distribution. The proposed model does not consider the inherent uncertainty of events and assumes that the TS of a target event is

[1] In Table 1, we assume that the membership function of "afternoon" is a parabola.

crisp. We distinguish two cases to establish the probabilistic model. First, we use a probability density function to model the uncertainty of a punctual event. Second, for the uncertainty of durative event, we employ two approaches, i.e., a two-dimensional PDF defined on a triangle domain, and a temporal covering probability function of the event. For durative events, the DTO may be crisp or vague; meanwhile, the temporal setting of an event may be without a length constraint, or with a determinate or vague length constraint. Hence, we can find six sub-cases, and establish the probability distribution function for each one.

## References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Worboys MF and Hornsby K, 2004, From objects to events: GEM, the geospatial event model. In: Egenhofer M, Freksa C and Miller H (eds.), *Proceeding of GIScience 2004*, *Lecture Notes in Computer Science*, 3234, Berlin, Springer, 327–343.