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# Representing time intervals in a two-dimensional space: An empirical study ☆

Yi Qiang [a,*], Martin Valcke [c], Philippe De Maeyer [b], Nico Van de Weghe [b]

[a] Department of Environmental Sciences, Louisiana State University, United States
[b] Department of Geography, Ghent University, Belgium
[c] Department of Educational Studies, Ghent University, Belgium

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ABSTRACT

*Objective:* Instead of the linear model (LM), time intervals can be represented by a two-dimensional (2D) model, which is called the triangular model (TM). Although the TM has been introduced for decades and applied in some areas, there still a lack of empirical studies on its usability. To fill this gap, this study aims to evaluate how people perform when using the TM to answer questions on time intervals, in comparison with using the traditional LM.
*Method:* Around 250 novice participants took part in the experiment, which consisted of a video training, a pretest and posttest. The video training introduced the basic knowledge of temporal relations and the two representations. The pretest allowed participants to practice the knowledge they have learned and receive feedbacks of the answers. In the posttest, participants′ accuracy and speed when answering the questions were recorded for analysis. The results of using the TM and the LM were compared in pairs. The null hypothesis is that the participants produce equal results with the two models.
*Result:* The results showed that the participants scored better and spent less time when answering questions with the TM, which rejected the null hypothesis. Moreover, the score and speed when they used the TM did decline in the questions containing a larger number of intervals. In contrast, the score and accuracy when they used the LM declined when questions containing a large number of intervals.
*Conclusion:*

- The TM is easy to learn. After a 20-min training, novice participants can use it to solve questions and produce satisfactory result.
- The TM is easy and efficient for visual queries of time intervals.
- The TM is easy to use for handling a large number of intervals.

*Implication:*

- The TM can be widely applied in analysing time intervals and linear data.
- Tools implementing the TM can be learned and used by novice users.



## 1. Introduction

A wide range of disciplines are confronted with the problem of handling information related to time, including information science [10], archaeology [27] and geography [20]. While time can be conceptualised and represented in

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* Corresponding author at: 1273 Energy, Coast, and Environmental (ECE) Building Louisiana State University, Baton Rouge, LA 70803-5705, USA. Tel.: +1 225 578 2279; fax: +1 225 578 4286.
*E-mail address:* yi_qiang@hotmail.com (Y. Qiang).

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diverse ways, the linear concept is predominant, which is reflected in many graphical representations such as time tables, chronological time lines and even the recent application in Facebook® (i.e. the Facebook time line). A segment of the time line is called a time interval, which is usually considered as the primitive of time. Up to now, considerable work has been done in handling time intervals in the areas of computer science and artificial intelligence [6,11,26]. The most well-known work is the qualitative interval algebra introduced by Allen [1] and the extension by Freksa [7]. Much seminal work about temporal reasoning is based on their theories. On the other hand, the research on visualisation and analysis of time intervals receives far less attentions. The visual representation of time intervals remains limited to linear segments along a one-dimensional (1D) time line, which is labelled as the linear model (LM) in this paper. Alternative representations of time intervals are available; e.g. the cyclic representations [15,32] and calendars [31]. They rather focus on the representation of specific aspects of time-dependent data, and are therefore not applicable in a broader range of contexts. In the LM, the second dimension is exploited solely to differentiate between the intervals of different events and thus has no metric temporal meaning. Therefore, the arrangement of linear segments can vary, depending on the sorting rules applied in the second dimension. This polymorphism prohibits the existence of a universal approach for visual analysis of time intervals. As a result, the linear time representation is most used for illustration, but rarely applied in analytical tasks of time intervals, especially exploratory data analysis, which greatly relies on data visualisation.

To overcome these difficulties, a two-dimensional (2D) representation of time intervals can be considered. This representation maps a time interval to a unique point in a 2D space. This 2D representation of time intervals was initially proposed by Ligozat [16,17]. According to Ligozat's approach, the vertical and horizontal axes respectively indicate the start point and end point of an interval. Later, Kulpa [12–14] proposed a 'midpoint-duration' approach, in which the horizontal axis indicates the midpoint and the vertical axis indicates the duration of an interval. He argues that this approach is advantageous in various applications and theoretical and has comprehensively elaborated its use in qualitative interval reasoning and interval arithmetic. Van de Weghe et al. [30] named this representation the triangular model (TM) and applied it to an archaeological use case. More recently, Qiang et al. have investigated the use of the TM in reasoning about imperfect intervals [21] and interval analysis [22–24]. Since the TM displays a set of intervals within a stable point structure, it offers special insights into interval distributions, particularly when a large amount of intervals are represented in it. Moreover, the TM supports a graphical query mechanism that relies on the manipulation of geometries in the 2D space. This query mechanism can help users interactively explore the dataset and examine the detected patterns. The practical use of the TM has been demonstrated by Qiang et al. [22,23], where the TM is implemented in a GIS to support spatio-temporal analysis of interval-based geographic data. In these two papers, the TM has been applied to analyse the interval data generated from a Bluetooth tracking system and imperfect interval data in an archaeological database. Available research stressed the potential of the TM in visualising and analysing time intervals. However, there is a lack of empirical evidence to ground its understandability and usability. To fill this gap, we have initiated an empirical study to evaluate the TM, in comparison with the conventional LM as a reference model. This paper summarises the design and results of this empirical study.

The remainder of this paper is structured as follows. Section 2 introduces the basic concepts of time intervals and the two models. Section 3 first introduces the theoretical base of the learning process, and next describes the design of the test and research process. In Section 4, the results obtained from the experiment are presented and analysed. In Section 5, we discuss the findings derived from our study. Section 6 summarises the contribution of this study and proposes avenues for future research.

## 2. The two time models

### 2.1. Linear model

A time interval is an extent of time, which can be the duration of an event or the lifetime of a person. In physics and computer science, a time interval is usually abstracted as a pair of real numbers $[I^-, I^+]$ with $I^- < I^+$. $I^-$ is the start point of $I$, $I^+$ is the end point, and the difference between $I^-$ and $I^+$ (i.e. $I^+ - I^-$) is the duration of the interval, which is denoted as $dur(I)$. The LM is derived from the experience and interpretation of time linearity, and intuitively represents a time interval as a linear segment along the time line. The two boundary points of the segment respectively indicate the start point and the end point of the interval (Fig. 1(a)). The length of the segment expresses the duration of the interval. Since time intervals may overlap and representing multiple overlapping segments in the time line may cause difficulties for visual

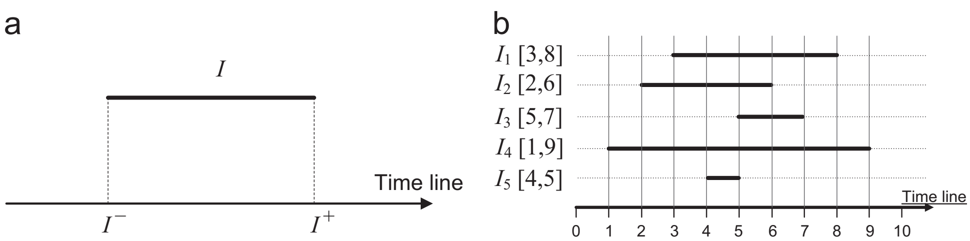


**Fig. 1.** Representing time interval in the linear model. (a) The representation of one interval and (b) the representation of multiple intervals.