# Representing time in language and memory: The role of similarity structure

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## ABSTRACT

Every day we read about or watch events in the world and can easily understand or remember how long they last. What aspects of an event are retained in memory? And how do we extract temporal information from our memory representations? These issues are central to human cognition, as they underlie a fundamental aspect of our mental life, namely our representation of time. This paper reviews previous language studies and reports a visual learning study indicating that properties of the events encoded in memory shape the representation of their duration. The evidence indicates that for a given event, the extent to which its associated properties or sub-components differ from one another modulates our representation of its duration. These properties include the similarity between sub-events and the similarity between the situational contexts in which an event occurs. We suggest that the diversity of representations that we associate with events in memory plays an important role in remembering and estimating the duration of experienced or described events.

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## 1. Introduction

We represent events as taking time. If we watch someone cook dinner, we are able to reconstruct the time this event took when later remembering it. Similarly, when we read descriptions of events, we have a sense of how long those events may last. For example, upon reading *the police arrested the suspect* or alternatively, *the police held the suspect*, somehow we understand that the latter event was longer than the former. How do we represent the duration of events we have experienced or read about? What aspects of the events represented in memory contribute to our sense of how long they take?

Here we review some relevant findings in language research and report a memory study addressing these questions. We build on previous theories within the psychology of time literature, in particular, those concerning memory-based time estimations (Block, 1982; Block & Zakay, 1997; Boltz, 2005; Grondin, 2010). When participants do not know beforehand that they will be asked for duration estimations, they will have to retrospectively reconstruct duration based on their memory of what happened (Block, 1974; Block & Reed, 1978; Ornstein, 1969). Previous studies have shown effects of memory content and processing context variability on these duration estimations. For example, Ornstein (1969) asked participants (one trial per

participant) to judge the relative length of two intervals that were in fact of the same clock duration. One instance of this interval was filled with few tones, whereas the other was filled with several tones. It was found that participants judged the interval filled with more tones as being longer than the other. Likewise, Block (1982) manipulated contextual changes by altering the physical environment or the task instructions under which the stimuli to be compared were first processed (e.g., attending to structural or semantic characteristics of the stimuli, or changing the room in which they were processed). Subsequent duration judgments revealed that contextual changes led to overestimation of duration. Based on findings of this sort, it has been proposed that stimulus complexity, the variability of contextual changes associated with the stimuli, and generally, the amount of information gleaned from the stimulus, determines retrospective duration estimations.

Retrospective estimations are similar to those elicited by language in that they are based on memory representations. Representations elicited by language rely on semantic memory representations built over time from our experience of events and the mapping of words onto event representations. Retrospective representations of events on the other hand, rely on the memory representations built from previous experience of the events. Such representations may emerge from a single experience of an event, as in most retrospective studies, but may also emerge from repeated experiences that are learned and encoded over time into memory schemas. We explore this link here, and attempt to establish some relationships between long-term representations in semantic memory and those that emerge from learning,

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on the assumption that learning mechanisms that initially apply when we first learn about events during the course of our lives are similar to those operating in learning stimuli for which we do not have already established memory representations. Much research in statistical learning has indeed reported parallel mechanisms across adults and children in extracting schemas or generalizations from regularities in the stimulus (Gómez & Gerken, 2000; Saffran, Johnson, Aslin, & Newport, 1999).

We therefore argue that some aspects of event representations in semantic memory, which help us to estimate their duration when they are described by language, also play a role when estimating duration of recently learned visual events. In particular, we argue that the similarity structure of the memory representations modulates our duration estimates in both of these domains, language and visual memory. Of course, pointing out some parallels across these domains does not entail that there will not be important differences. Indeed, it is almost certain that schemas in semantic memory have many more properties than those emerging from a few exposures to novel visual events, given the multidimensional nature of events, the multiple contexts in which they can occur and the hierarchical structure that they afford (Zacks, Speer, Swallow, Braver, & Reynolds, 2007), all aspects that likely need longer periods of exposure and memory consolidation than those present in a single learning study. Yet, such parallels may turn up to be illuminating and guide further research.

### 1.1. The puzzle

Research in mental models has suggested that as we read discourse or sentences, we build a mental model of the temporal relationships between events that resembles properties of the situations described (Kelter, Kaup, & Claus, 2004; Zwaan & Radvansky, 1998; Zwaan, Radvansky, Hilliard, & Curiel, 1998). For example, longer temporal distances between events have been shown to take longer to process (Gennari, 2004; Zwaan, 1996) and information from temporally more distant events in the narrative takes longer to retrieve (Kelter et al., 2004). This research suggests that mental representations of temporal distance are analogical with the characteristics of the world described. However, to what extent can our mental representations be analogical with actual time? The representations that we entertain during reading or remembering are clearly not a copy or a re-enactment of the actual events described or experienced, as for instance longer described duration does not lead to a linear increase in processing cost: it does not take a lifetime to process a sentence like *John searched for the right woman all his life*. Rather, these memory representations are somehow temporally compressed, activating salient or typical characteristics of the events being talked about. The question therefore arises what aspects of the events are retained in memory and activated during processing, either when retrieving word meanings and composing the representation of the event described or when retrieving an event from memory.

### 1.2. Some observations from language research

In an attempt to answer the question above, Marta Coll-Florit and one of the present authors (Coll-Florit & Gennari, 2011) investigated the processing of event descriptions that differed in the duration attributed to the referred events, and correlated their processing times with measures that characterized semantic properties of the events in long-term memory. In a semantic decision task (where participants were asked to indicate whether stimulus phrases made sense), we directly compared the response times to phrases such as *to owe money* and *to lose money*, which differed in the duration of the event described. We found that indeed verb phrases that refer to durative events (*to owe money*) took longer to process than phrases referring to non-durative events (*to lose money*). This suggested that longer events activate event knowledge that is more costly to access or retrieve. Similar results were found in a second study with Spanish verbs that undergo changes in interpretation (or sense) from longer to shorter events as a function

of imperfective or perfective morphology (e.g., *conocía/conoció 'knew/ learned'*). Interestingly, processing times of these verbs and verb phrases positively correlated with the duration attributed to the referred events in an arbitrary 1–7 scale.

What drives the differences in processing time in these studies? And why does event duration correlate with processing times? To begin to address these questions, we conducted a free association study often used in memory research to establish the words that come to mind upon reading our stimulus verbs and phrases (Coll-Florit & Gennari, 2011). Analyses of these associations showed that durative events elicited associations of a more diverse nature than non-durative events: a non-durative event brings to mind mostly other events and objects (e.g., for *losing money*, associates would be *money, gambling, mistake, drop*), whereas durative events elicit a variety of semantic types including states and properties as well as other events and objects (for *owing money*, associates would be *slow to pay, worried, loan, gratitude*). We also conducted a corpus study investigating the sentential contexts in which the verbs used in our phrasal study tend to occur. The verbal contexts in which verbs occur provide information about the real world situations in which the events referred to by the verbs occur, as they indicate the participants, objects, locations, etc., with which the events co-occur. The verbal contexts are thus a proxy for the properties of real world situation contexts in which events occur. We computed the Euclidean distance between these contexts, a measure indicating how similar the situation contexts are, thus providing a measure of how diverse the verbs' memory associations built over time through experience of the events are. We found that the similarity of the non-durative contexts is larger than that of the durative ones, consistent with the idea that the contexts in which durative events occur are more variable and thus, less similar to those of all other verbs. Importantly, the Euclidean distance of a verb in semantic space and a measure of variability between memory associations from the association study correlated with both duration estimates for the stimuli and their processing times. These results demonstrate a link between the diversity of situational contexts and memory associates of event descriptions with both estimated duration and processing times, suggesting the possibility that these two behavioral measures are driven by properties of the representations established in semantic memory.

The results described here have been extended to different sentential stimuli for which the event described does not depend on lexical meaning alone. In fact, Gitte Joergensen and one of the present authors (Joergensen & Gennari, 2013) compared the interpretation of the same action verbs in different contexts that implied long and short durations (e.g., *to alter a dress for one hour* vs. *three hours*). We found that the time it takes to retrieve the event described in a memory task depended on duration and also correlated with the diversity or variability of the memory associations generated by the discourse situation. This study, together with the study manipulating Spanish morphology mentioned above, addresses a concern in many previous studies, namely, that the interpretation of duration is often correlated with different verb classes or lexical meaning. However, how long we interpret an event to be depends on its context, and this interpretation does not always correlate with verb classes, and instead depends on whatever cues are available in the context, thus, highlighting the orthogonal and distinctive nature of a given interpretation based on event knowledge and grammatical features (Metusalem et al., 2012). Taken together, these results suggest that the diversity of associations linked to events in semantic memory may be responsible for their processing cost. Although the definitive answer for why this might be the case awaits further research, our results suggest that the cost of retrieving event knowledge or schemas may result from the effort of collecting diverse properties and associations from memory, i.e., properties that come from different semantic domains and occur in diverse, dissimilar contexts.

Drawing a parallel to event memory, these results bring up the possibility that the diversity of associations for events in memory may be related to the duration attributed to them. Why should this be the