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What is Universal in Perceiving, Remembering, and Describing Event Temporal Relations?

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Abstract

What temporal relations do humans use to form dynamic mental representations of events? In the fields of artificial intelligence and computational linguistics, some have proposed an interval based representation, in which two events could be related in time by seven primitives. The seven primitives are BEFORE, MEET, OVERLAP, START, DURING, FINISH, and EQUAL. In the present study, perception, memory, and language about event temporal relations were investigated. The results showed that BEFORE, MEET, and DURING seem to be prevalent in the temporal experiences across a range of cognitive tasks, despite that there is variability with respect to different cognitive tasks.

Event Temporal Representation

Time is an inherent dimension of event representations (Freyd, 1987; Lu, 2003; Schank & Abelson, 1977; Zacks & Tversky, 2001; Zwaan, Magliano, & Graesser, 1995). In everyday life, there are many goal oriented activities that require an understanding of fine-tuned and subtle timings of events, as in the case of *making chicken soup*, *operating certain mechanical devices,* and *making a camp fire*. There are also many events that are loosely related, as in the case of *recalling some quarreling couple while dinning at a restaurant, hearing a loud sound from a house while taking a walk,* and *seeing a squirrel running on the electrical wire while walking past a fence.* How do people construct the temporal relations of events that may or may not be related in an overarching conceptual structure? For the purpose of this paper, the term event will be used as a covering term for both intentional actions (as in the case of an agent *making chicken soup*) and events that are not governed by the goals of an agent (as the in the case of *oil turning smoky*).

Previous research suggests that the plan and goal structures of everyday activities play an extremely important role in the encoding and retrieval of event temporal relations (Lichtenstein & Brewer, 1980). When people are asked to recall the sequence of events, they often place events in an order that maps onto the logical inferences derived from the goal and causal constraints instead of the actual order in time (Bauer & Mandler, 1989; Lichtenstein & Brewer, 1980). It is notable that the type of the events investigated in these studies tends to be the case where one agent manipulates one object and enacts one action at a time (Lu, 2003), whereas the examples in the previous paragraph seem to suggest that humans often experience events that have overlap in time. Additional research is needed to specify the details of how the plan and goal based theories could account for events overlapping in time.

How are events represented in temporal dimension? There are two types of primitives for temporally representing events (Allen, 1984; 1991). A point based representation captures events as being indexed as points in time. One event can be a single point in time, as in the case of *a sunrise at 4:30* or a *hiccup.* There are many singular point expressions in natural language (Moens & Steedman, 1988; TerMeulen, 1995); the events described in these point expressions appear to be conceptually instantaneous. A point based representation can also represent non-instantaneous events with a set of points in time. For example, a person's cleaning the fish tank can have a beginning at 2:15 and an end at 2:35 p.m. Its sub-event *getting the supplies* begins at 2:16 and ends at 2:19 p.m. Each of these events has points in time marking the beginning and the end.

In contrast, an interval based representation captures events as durations that may gloss over exact time points. Thus, the interval of *getting the supplies* occurred during the interval of *cleaning the fish* tank, without any specification of the exact points in time that mark the beginning and end points of events. Psychological studies have reported that people have a grasp of the range of time during which an event occurs (Golding, Magliano, & Hempill, 1992; Loftus, Schooler, Boone, & Kline, 1987). For example, John may not know exactly at which points of time he opens his car door, yet he knows it takes two or three seconds to open it. The chief theoretical challenge lies in specifying how to relate the intervals of events and how to draw inferences about the relative timing of events on the basis of interval constraints.

In the fields of artificial intelligence and computational linguistics, Allen (1984; 1991) developed a formalism that captures the various temporal relations between two events that are represented in intervals. Figure 1 provides an illustration of these seven relational structures: BEFORE, MEET, OVERLAP, START, DURING, FINISH, and EQUAL. In Figure 1, each double-headed arrow represents an event that occurs over some time interval, and each arrow-head represents either the beginning or the end of an event. The relation between each pair of events is described by one of the seven predicates. The BEFORE relation means that one event is prior to another event and that two events do not overlap in any way, whereas the MEET relation means that one event starts at the time another event ends. START means that two events share the same beginning, but one ends before another, whereas EQUAL means that two events share the same interval and the same beginning and end. These primitives are essential for constructing a computational system of event representations (Allen, 1984). To what extent are Allen's seven relations used as conceptual primitives in event temporal representation?

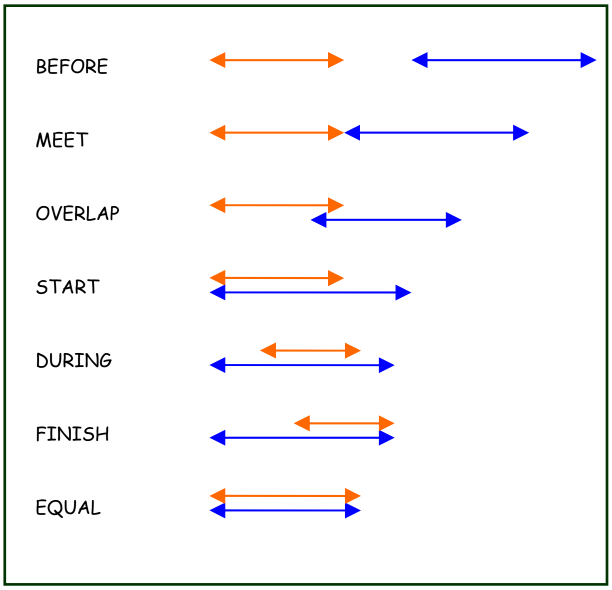

Figure 1: Temporal Representations by Allen (1991).

The formalism laid out in Figure 1 may capture some intuitive aspects of human temporal reasoning. For example, there is some evidence that endorses the distinction between BEFORE and MEET. Kate, a language found in Papua New Guinea, makes grammatical distinctions between the following two types of events: (a) events that are separated by a period of time with nothing significant, and (b) events that have successive temporal relations (Grime, 1975; but see Zwaan & Radvansky, 1998, pp. 176). In the Newtson task, participants are asked to segment a videotape of an activity into events and their parts (Newtson & Engquist, 1976). Participants are told to press the spacebar when they think one event ends and another begins. This methodology implicitly endorses MEET as the typical temporal experience encountered in the world.

Gestalt laws of perception postulate that forms are easier to process psychologically if they have more redundancy in pattern and permit fewer alternative forms. Conversely, forms are harder to process psychologically if they have less redundancy in pattern and render more alternative forms (Garner, 1974; Rock & Palmer, 1990). Examining Figure 1 based on Gestalt laws of perception, the complexity of the seven temporal relations seems to vary. For example, EQUAL may not have alternative forms, whereas START may have several alternative forms pending on the intervals of events. It is reasonable to infer that humans may capture some relations easily, but have some other relations confused (Lu, Graesser & Wolff, 2003).

In this paper, four experiments are reported to investigate the temporal relations people tend to construct. In Experiments 1 and 2, animated events of fish swimming were presented, and judgments of temporal relations were made. In Experiment 3, events were presented linguistically, and a production task was used. In Experiment 4, three separate sentence sorting tasks were conducted to see what semantic distinctions humans make when they describe events and their temporal relations.

Experiment 1: Perception of animated events

Experiment 1 investigated which temporal relations humans tend to construct out of the 7 primitives in the context of event perception. Participants were presented with animations of fish swimming events made in an animation program, called 3D Studio Max. Participants were asked to make judgments about which temporal relation out of the 7 choices best captures the animated events they saw.

Participants There were 51 college students at the University of Memphis who participated for course credit.

Materials Forty-two 3D animations were made using an animation program called 3D Studio Max release 5. Each animation depicted two fish of different colors and sizes swimming in the water. The spatial trajectory of the fish swimming was a straight line. For each relational structure in Allen's scheme, there were two sets of animations. One set of animations holds the distances of fish swimming constant but varies the speed of fish swimming, whereas the other set of animations holds the speed of fish swimming constant but varies the distances. For each set, there were three different perspective combinations: horizontal – horizontal, vertical - vertical, and horizontal - vertical.

The animation quality is near photorealistic. Each animation was 25 seconds in length and was run at approximately 30 frames / second.

Procedure Each participant was seated in front of a Pentium computer, which used MediaLab 2000 (Jarvis, 2000) to display the materials. Participants were asked to make judgments concerning how fish swimming events were related in time, as discussed below.

Participants were shown Figure 1 (without linguistic labels), and steps were taken to make sure they understood Figure 1. Participants were instructed to choose one relation out of the seven which best captured how two animated events were related in time. Before the animations were launched, participants were told that they could only have one viewing of each animation and that the screen with 7 choices would automatically pop up after each animation. Participants made choices by clicking a number that was next to the temporal relation.

Each participant received the same order of the temporal relations depicted in a diagram throughout the experiment. There were 20 sets of orders in which the temporal relations were presented. For each participant, the animations were presented in a random order.

Confusability Analysis Entropy was used to calculate the conceptual distance between each pair out of the 7 temporal relations. The construct of entropy originated in information theory, which is a mathematical formulation of the uncertainty in a data set (Shannon, 1948). In the current study, each item may have 7 types of responses. For a given item, the following formula computes how likely one relation is confused with another one.

$$E_i = -\frac{\sum_{i=1}^{N} p_i \ln p_i}{\ln N}$$

The p_i refers to the proportion of times a given choice is selected out of the N possible choice items.

The entropy gives an index of how similar any two given structures (e.g. BEFORE and MEET) appeared to participants. A similarity matrix can thus be constructed, and then entered into the multidimensional scaling program implemented in SYSTAT version 9 with Young's S-STRESS scaling method (Wolff & Song, in press).

Results and Discussions The probability of people making the correct judgment of temporal relations was .80 on average. The error rates of the seven relations were the following: BEFORE (.20), MEET (.29), OVERLAP (.33), START (.15), DURING (.29), FINISH (.26), and EQUAL (.07). The EQUAL relation has the lowest error rates.

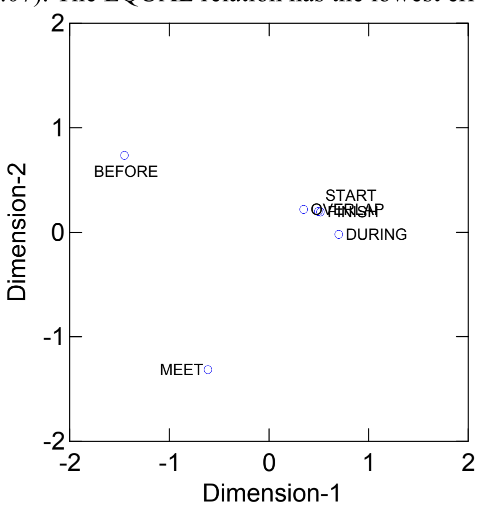

Figure 2: MDS Solution of Perception Task.

The confusability index was computed in entropy E_i. The similarity matrix was constructed using the entropy formula. This similarity matrix was submitted to the multidimensional scaling program. The MDS solutions in Figure 2 showed the following pattern of structure clustering yielded from the perception task. The similarity matrix was fit by a 2-dimensional MDS solution, with a very low stress value (.01), and a high proportion of variance accounted for (R^2 = 0.99). The seven temporal relations in Figure 1 were clustered into three main groups: BEFORE, MEET, versus (OVERLAP, FINISH, START, EQUAL, DURING).

The results showed that people tend to make distinctions whether events have overlap in time, as BEFORE and MEET stand out from the rest of the five temporal relations. People seem to make mistakes often among the five temporal relations that have overlap in time.

Experiment 2: Perception of animated events in the speeded condition

In Experiment 1, participants were given the luxury of focusing on two events. Experiment 2 investigated whether the effects observed in Experiment 1 are the result of people having enough attentional and cognitive resources during event perception. The animations used in Experiment 1 were presented at a faster rate (see Graesser & Nakamura, 1982; Reiger & Zheng, 2003, for the same method). Participants made judgments of the animated events in the same way as Experiments 1.

Participants There were 40 college students at the University of Memphis who participated for course credit.

Materials The same set of 42 3D animations used in Experiment 1 was used in Experiment 2. The animations were speeded up using an animation program called VirtualDub. The animations were displayed 30 frames / second in Experiment 1, whereas the animations was speeded to 75 frames / second in Experiment 2.

Results and Discussions The probability of people making the correct judgment of temporal relations was .66 on average. The error rates of the seven relations were the following: BEFORE (.34), MEET (.40), OVERLAP (.40), START (.23), DURING (.41), FINISH (.43), and EQUAL (.10). Compared with Experiment 1, the error frequency increased in Experiment 2.

The similarity matrix was constructed in the same way as Experiment 1, and then was submitted to the multidimensional scaling program. The MDS solutions showed the same pattern of structure clustering yielded as in Experiment 1. The seven temporal relations were clustered into three main groups: BEFORE, MEET, versus (OVERLAP, FINISH, START, EQUAL, DURING). The relational clustering in Experiment 2 did not differ from Experiment 1. Whether two events had overlap in time was again used to distinguish BEFORE and MEET from the rest of the temporal relations. Experiment 2 ruled out the possibility that the pattern observed in Experiment 1 was merely the effect of attentional allocation.

Experiment 3: Memory of everyday event time using a drawing task

Experiments 1 and 2 investigated the perception of events and their temporal relations. The question at this point is whether the relational clustering in the perception of everyday events will also be observed in the memory of everyday activities. In the perception judgment experiments, participants were provided Allen's seven relations. We were curious to find out whether the same pattern will be observed if Allen's seven relations are not provided. Participants were presented pairs of everyday events that were coded to have the temporal relations in Allen's representation. Participants read pairs of events, and then drew which temporal relation in Allen's representation best captures the events they read.

Participants There were 34 college students at the University of Memphis who participated for course credit.

Materials A sample of events from everyday activities were collected. To ensure generality, the events were chosen from a wide range of everyday activities. Some examples include: driving a car, grocery shopping, cashing a check, and so on. Three raters were trained to understand Allen's representation, and made judgments on how each two events were related in time separately. The materials used in the experiment were the items agreed upon by all three judges.

For every pair of events, a supporting context was provided. An example is below:

Context: Imagine a passenger at an airport.
Events: She went through the security screening.
Her carry-on bags were x-rayed.

For each of the 7 temporal relations in Allen's proposal, there were 10 test items. There were 70 test items in total.

Procedure Participants were introduced how to represent an event occurring over some time with beginning and end points. Then they were given two examples: one indicating one event occurring before another, the other indicating one event occurring in the middle of another. The events were presented on A4 size papers, and space was provided for drawing. Allen's 7 temporal relations were used to code the drawings. The inter-rater agreement was 96%.

Results and Discussions The probability of people making the correct judgment of temporal relations was .29 on average. The error rates of the seven relations were the following: BEFORE (.31), MEET (.83), OVERLAP (.82), START (.95), DURING (.73), FINISH (.83), and EQUAL (.51). The probability of drawing START was significantly lower than chance, whereas the probability of drawing other six relations was higher than chance. For example, compared with the probability of drawing FINISH, the probability of drawing START are significantly lower, $t(33) = 3.021$, $p < .005$, using Bonferroni correction.

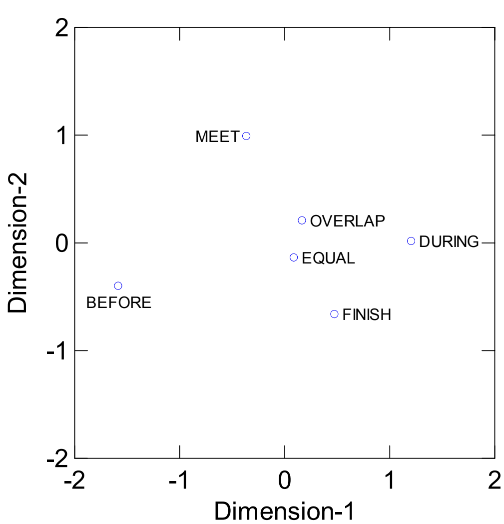

Figure 3: Drawing MDS Solution.

The similarity matrix, which was used to fit a 2-dimensional MDS solution, does not include START. The resulting MDS solution had a very low stress value (.01), and a high proportion of variance accounted for ($R^2 = 0.99$). The six temporal relations were clustered into three main groups with varying distances: BEFORE, MEET, versus (OVERLAP, FINISH, DURING, EQUAL). Compared with the MDS solution in the perception experiments, the distances among the four relations that have overlap in time are farther apart in the drawing task. Nonetheless, the clustering formed by the rest of the 6 temporal relations, are not incompatible with the previous perception tasks. Whether two events have overlap in time continued to be an important dimension in the memory of everyday events.

Experiment 4: Semantic organization of temporal lexemes

Children tend to describe an event when they answer questions about time (Nelson, 1996). Consider such an example. *When do you go to bed? When mommy comes to get me.* The child did not say something like *at night*. This example suggests that how we talk about time is correlated with how we think of time (Gentner & Boroditsky, 2001). Does the pattern of event temporal relations observed in the perception and memory of events reflect in the language about event temporal relations?

Experiment 4 investigated the semantic clustering of temporal event language when college students performed linguistic sorting tasks. Participants were presented sentences with temporal words embedded in them. They sorted the sentences into groups which shared similar meanings of the embedded words. The central question is whether the words would cluster according to theoretically interesting dimensions. Three experiments were conducted separately for verbs, adverbs, and prepositions plus conjunctions.

Experiment 4 (a): Verb sorting

Participants There were 27 college students at the University of Memphis who participated for course credit.

Materials A list of verbs and their synonyms encoding how two events are related in time was assembled from several thesauruses. Each of the 17 verbs in (4a) was printed at the top of a 4" x 6" index card. Below each verb were printed two sentences that illustrated the use of the verb. The example sentences were selected from the British National Corpus.

Procedure Participants were asked to read the sentences on the verb index card, and then sort the verb index cards into as many or as few groups as they felt appropriate. They were told that the cards in each group should have "essentially the same meaning".

Results The frequency of each pair of words co-occurring in the same group was scored and assembled in a word-pair co-occurrence matrix. The MDS solutions showed a pattern of verb clustering. The sorts were fit by a 2-dimensional MDS solution, with a very low stress value (.18), and a high proportion of variance accounted for ($R^2 = 0.87$). The verbs

in (4a) were sorted into three main groups as shown in Figure 4:
BEFORE – type verbs (anticipate, be before, foresee, go before, and precede);
AFTER – type verbs (come after, go after, follow after, succeed, and result);
DURING – type verbs (coincide, concur, co-occur, ensue, fall together, go with and overlap).

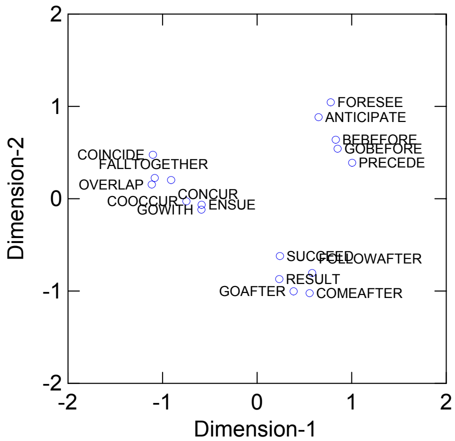

Figure 4: Verb Sorting MDS Solution.

Experiment 4 (b): Adverb sorting

There were 58 undergraduates at the University of Memphis who participated for course credit. Materials and procedure were the same as Experiment 4 (a).

Results The MDS solutions showed a pattern of adverb clustering. The sorts were fit by a 2-dimensional solution, with a very low stress value (.13), and a high proportion of variance accounted for (R^2 = 0.94). The adverbs in (4b) were sorted into three main groups:
BEFORE – type adverbs (before, beforehand, earlier, formerly, in advance, previously and sooner;
AFTER – type adverbs (after, afterwards, later, later on, next, sooner or later, and subsequently);
DURING – type adverbs (at the moment, at the same time, concomitantly, concurrently, contemporaneously, for now, in chorus, in concert, in the meantime, in the same breath, in time, in unison, instantaneously, meanwhile, on the beat, simultaneously, synchronously).

Experiment 4 (c): Preposition sorting

There were 76 undergraduates at the University of Memphis who participated for course credit.

Results The MDS solutions showed a pattern of preposition clustering. The sorts were fit by a 2-dimensional solution, with a very low stress value (.14), and a high proportion of variance accounted for (R^2 = 0.91). The prepositions in (4c) were sorted into three main groups:
BEFORE – type prepositions (before, prior to);
AFTER – type prepositions (after, soon after, as soon as, until, pending, by);
DURING – type prepositions (just as, when, as, along with, while, amid, during, in the course of, throughout, over).

Discussions of Experiment 4

Across grammatical categories, Experiment 4 showed that people are predisposed to three types of temporal relations when they talk about time. The results are compatible with the proposals by Wierzbicka (1973) in linguistics and Graesser et al. in psychology (Graesser, Wiemer-Hastings, & Wiemer-Hastings, 2001). The mapping between linguistic primitives and Allen's primitives may be more complex than the MDS solutions suggested. Nonetheless, the evidence in linguistics may indicate some alignment between the linguistic clustering and the conceptual clustering that emerged from the previous experiments.

The linguistic primitive AFTER may correspond to some aspects of MEET. Wierzbicka and others have noted that BEFORE and AFTER encode somewhat different temporal conceptions of events (Thompson & Longacre, 1985, but see Wierzbicka 2002; Wierzbicka, 2002). One difference is that the event in the BEFORE clause usually does not begin until the event in the main clause ends, whereas AFTER does not have this constraint. Consider the following two examples: (a) *John took out the water pipe before he drained the fish tank* and (b) *John washed the dishes after he cooked the dinner*. The two events in example (a) have to occur one before another, whereas *washing the dishes* in example (b) could occur before *finishing the cooking.* There is some empirical evidence in support of this conjecture. In a separate sentence rating task we conducted, two types of *after* sentences were selected from a corpus. One type refers to the situation where one occurs after another with a time interval in between, whereas a second type refers to the situation where the beginning of one event is after another event but both events have overlap in time. There were significant differences between the likelihood ratings of whether the two events described in each sentence have overlap in time.

Summary and Discussions

Four experiments investigated how people piece together events that may or may not have an overarching conceptual structure in a range of cognitive tasks. The results suggested that the distinctions made among BEFORE, MEET, and DURING seem to be prevalent when people perceive, remember, and describe how events are related in time.

However, there is apparently some variability in the MDS solution yielded from different cognitive tasks. When people had to linguistically encode and retrieve events, the event temporal representations may be harder to construct. The MDS solution in Figure 3 indicated the trend that BEFORE, MEET, and EQUAL are more likely to be constructed than other temporal relations. BEFORE, MEET, and EQUAL may be easier for humans to process because they have inherent simplicity, symmetry, and good forms, which are hallmarks of the Gestalt Law of Prägnanz (Rock & Palmer, 1990).

It is not clear at this point how the linguistic primitives map onto the primitives in perception and memory tasks. According to the relational relativity hypothesis, language affects thought in more abstract domain (Gentner & Boroditsky, 2001; Gentner, 2003). Temporal constructs are abstract, this points to the possibility that the way we talk about time affects how we encode the temporal aspects of events. The MDS solutions in the current study indicate some alignment among the primitives across different cognitive tasks. However, the alignment may be more complicated and needs further investigations.

It appears that BEFORE, MEET, and DURING are used in the perception, memory, and linguistic experiences of temporal representations. When the representations are harder to construct, for example, in the case of linguistic retrieval of event representations, people are more likely to mistake one temporal relation with another. In further studies, it is necessary to investigate the cognitive principles that constrain the constructions of temporal event relations.

Acknowledgments

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