Uniquely Human Temporal Thoughts

İsa Kerem BAYIRLI, isakerem@gmail.com

TOBB University of Economics and Technology, Ankara

1. Introduction

Life on Earth will eventually come to an end. The thought expressed in the previous sentence is about a point in time that is, most likely, not known to the individual entertaining the thought; it is a thought about a non-specific temporal point in the future. This paper is concerned with the nature of such thoughts. We claim that the capacity to mentally represent thoughts about non-specific temporal intervals in the past and in the future is a unique aspect of human cognition. We suggest that this capacity is a consequence of the fact that human grammar defines/generates sentences involving binding of temporal variables and quantification over temporal intervals.

In classical temporal logic originating in Prior (1967), tense is analyzed as a sentential operator which relativizes the truth value of a sentence to points in time. Past tense is true of a sentence at the time of evaluation just in case there is a time preceding the evaluation time at which the sentence holds. Future tense is true of a sentence at the time of evaluation just in case there is a time following the evaluation time at which the sentence holds. In natural languages, the evaluation time of a sentence is typically understood to be the moment of utterance, which we indicate with the contextual parameter *now*. Under this approach, the sentences "John danced" and "John will dance" have the logical forms shown in (1), where "<" denotes precedence and the time of evaluation is fixed by the contextual parameter *now*.

(1) a. $\exists t.\ t < now\ \&\ dance(John, t)$

b. $\exists t.\ now < t\ \&\ dance(John, t)$

Reichenbach (1947) notes that there is more to the representation of temporal relations encoded in linguistic expressions than just the event time and the speech time. The semantic analysis of linguistic constructions related to time requires access to another dimension of temporality, the reference time (also called the topic time, Klein 1994), against which the event time is to be evaluated. Under this approach, time-related constructions in natural languages relate the topic time to the speech time, which is what Tense is about, and the event time to the topic time, which is what (grammatical) Aspect does (see Hornstein 1993 for an elaboration of Reichenbach's system to account for the distribution of complex temporal adverbs as well as the temporal relations inside sentences with embedded clauses). Consider the difference between the sentences in future and future perfect (2a-b), and in past and past perfect (2c-d).

(2) a. John will have finished his homework at 6 pm. (Future Perfect)

b. John will finish his homework at 6 pm. (Future)

c. John had finished his homework at 6 pm. (Past Perfect)

d. John finished his homework at 6 pm. (Past)

Intuitively, (2a) makes reference to a point in the future (the topic time) before which John is expected to be done with his homework (the event time). This point of reference, which follows the speech time due to the future tense, is made explicit by the time adverb "6 pm" and the event time is understood to precede this temporal interval characterizing the topic time. In (2b), on the other hand, the absence of perfect means that the topic time (i.e. "6 pm") is simultaneous with the event time (the time at which John finishes his homework). Below, we provide a representation of the interaction between future and perfect on the time line (S = Speech time, E = Event time, T = Topic time).

(3) a. _____S_____E_____T______ (Future Perfect)

b. _____S___________E,T____ (Future)

The presence of the perfect aspect indicates that the event time precedes the topic time while its absence implies that the event time coincides with the topic time. Crucially, in both cases, as a function of the future tense, the topic time follows the speech time.

The situation is quite similar with past versus past perfect. In this case, too, the presence of perfect indicates that the event took place before the topic time. In (2c), for instance, "6 pm" is the topic time, before which John managed to complete his homework (the event time). In (2d), the absence of perfect has the consequence that the topic time ("6 pm") and the event time (the time at which John finishes his homework) coincide. The interaction between the speech time, the event time and the topic time in the context of past vs past perfect can be represented on the time line as in (4):

(4) a. _____E_____T_____S_____ (Past Perfect)

b. _____E,T__________S_____ (Past)

It is important to note that there is more to the topic time than just the existence of a temporal point before or after the speech time. The topic time denotes **a specific temporal point/interval** preceding or following the speech time "given by the context of speech" (Reichenbach, 1947, p. 288). In other words, tense is a referential category denoting a specific temporal point/interval rather than a quantificational category requiring only that a temporal point/interval on the time line exist. There is independent evidence that this analysis of tense is on the right track. Partee (1973) observes that the quantificational (i.e. Priorian) approach to tense delivers wrong truth conditions for (at least some) negated sentences in the past tense in English. Consider (5), which can be given two distinct quantificational analyses shown in (6a-b).

(5) I didn't turn off the stove

(6) a. $\neg(\exists t < \text{now}: \text{turn\_off}(\text{the speaker, the stove}, t))$

b. $\exists t < \text{now}: \neg(\text{turn\_off}(\text{the speaker, the stove}, t))$

The logical form in (6a) expresses the thought that it has never been the case that the speaker has turned off the stove. This is too strong a meaning to characterize what (5) says given that (5) is compatible with the speaker turning off the stove at some point in the past. (6b) indicates that there is a point in the past at which the speaker did not turn off the stove. This is true, but trivially so. It is trivially true that there was some interval in the past at which the speaker did not turn off the stove. That is to say, the truth conditions associated with (6b) are too weak to provide an accurate semantic analysis. (5) seems to have an interpretation that corresponds to the claim that there is **a specific interval** within which the speaker failed to turn off the stove, say the interval right before the speaker left the house. To capture this reading, Partee suggests that tense should be analyzed as a free variable, one that is not bound by any quantifier, that gets its value directly from the context. The assignment of free (i.e. non-bound) temporal variables to temporal intervals in the context is achieved via an assignment function, denoted below as *g*. Under this assumption, a Partee-style analysis of (5) can be given as (7), where *right_before_leaving_home* is the specific temporal interval within which the speaker was to turn off the stove.

(7) ¬(turn_off(the speaker, the stove, t)) & t < now

where g(t) = *right_before_leaving_home*

Crucially, unlike (6a-b) above, (7) contains no quantifiers binding temporal variables. It relies on the direct assignment of free variables in the sentence to contextual entities, in this case to temporal intervals. The presence of the past tense guarantees that the interval that corresponds to the free variable comes before the utterance time.[1]

There are also languages in which tense operates in a quantificational manner. In Javanese, a Malayo-Polynesian language of Indonesia, the auxiliary "tau" is used to "talk about events that happened at some (unspecified) time in the past. Pragmatically, the emphasis is on the fact that the subject has had this experience at least once, rather than when exactly this happened." (Chen et al., 2020, p. 710). Some strong evidence for this claim comes from the fact that sentences involving this morpheme have precisely the readings that the referential past tense in English is argued to lack. (8a) shares a logical structure with (6a), where negation out-scopes the existential temporal quantifier. ("A >> B" means that the operator A takes scope over the operator B). In (8b), we find the existential quantifier taking scope over negation, which mirrors the order of logical operators in (6b). (Chen et al., 2020, pp. 725 – 726).

(8) a. Wong londo gak tau mangan sego (¬ >> ∃)

person western NEG PST eat rice

'Foreigners have never eaten rice.'

b. Pak Wanan tan gak mangan sego (∃ >> ¬)

Mr. Wanan PST NEG eat rice

'Mr. Wanan has sometimes not eaten rice.'

Moreover, "tau" cannot be used referentially the way that the past tense in English can. The Partee-example we have seen in (5) referring to a specific interval in the past is judged to be

[1] There are also quantificational approaches to tense in English (Ogihara, 1996; von Stechow, 2009) as well as approaches that build on the idea that past in English is ambiguous between a referential and a quantificational denotation (Grønn & von Stechow, 2016). In what follows, we shall take a closer look at languages that have a specialized tense morpheme for the existential past tense.

unacceptable in the presence of this auxiliary morpheme. Such sentences are felicitous only when "tau" is eliminated from the sentence (Chen et al., 2020, p. 729).[2]

(9) aku kok rung (# tau) mateni kompor yo!

1SG PRT not.yet PST die stove yes

'I didn't turn off the stove!'

Chen et al. (2020) claim that, in addition a quantificational auxiliary, Javanese also has a (null) referential tense morpheme, which accounts for the acceptability of (9) in the absence of "tau". That is, referential and quantification tense morphemes co-exist in the grammar of Javanese. In what follows, we shall take this distinction between ways of representing time in grammar as our point of departure for proposing a hypothesis about how human temporal cognition might differ from that of other animals. More specially, taking inspiration from Bolender's proposal that representing quantificational structures is a human capacity (Bolender, 2016; Bolender et al., 2008), we claim that while referential tense is shared between non-human and human primates, quantificational tense is unique to human cognition.

2. Temporal Cognition in Primates

We have discussed two ways of representing temporal relations in natural languages. We have seen that they are both needed to express semantic properties of tensed sentences. Below we repeat how these two approaches represent time in the past and in the future:

(10) The referential approach to tense

dance(John, t) & t < now

dance(John, t) & now < t

with "g" as the assignment function from free variables to temporal intervals

[2] In (9), the string "(# tau)" is intended to convey that the presence of the morpheme "tau" makes an otherwise felicitous sentence infelicitous.

(11) The quantificational approach to tense

$\exists t.\ t < now\ \&\ dance(John, t)$

$\exists t.\ now < t\ \&\ dance(John, t)$

In this section, we review some of the evidence suggesting that (non-human) primates can entertain temporal thoughts. We claim, moreover, that such thoughts have the structure implied in the referential theory of tense rather than in the quantificational theory of tense. That is, animals can represent a specific temporal interval in the past or in the future, in a sense to be clarified below. However, humans and only humans are capable of temporal thoughts about non-specific temporal intervals in the past or in future, which is enabled by their capacity for temporal quantification.

It is controversial whether animals can entertain thoughts locating events in time. Hoerl & McCormack (2019) distinguish between two systems of temporal cognition: a temporal updating system and a temporal reasoning system, only the latter of which, they claim, is unique to humans. The temporal updating system relies solely on a current representation of how things are in the environment. Upon receiving a new piece of information about the world, an animal restricted to temporal updating "simply records the new, changed state of affairs, rather than also representing that things were previously different from how they are now. Thus, the temporal updating system operates with a model of the world that concerns the world only ever as it is at present. Other times, and how things are at other times, are not represented in the system." (p. 2) The temporal reasoning system, on the other hand, "operates with a model of the world that includes a temporal dimension. That is to say, the model contains information not just concerning the world as it is present, but also information about states of affairs different from those existing in the present, which existed in the past or will exist in the future." (p. 3) Imagine an animal in the jungle coming across a tree that it has never seen before, a fruitful fig tree. This animal updates its information state about this new food source and carries this information forward in time in memory. At some later point, let's say, the animal revisits the tree only to find that it is completely empty now. If this animal is a species of temporal update, it can only represent this new state of affairs, i.e. that the tree is empty now, and carry this new information state forward in time. If it is a species of temporal reasoning, however, this animal can represent the thought that the tree had fruit in it in the past but is empty now. In fact, this animal may also represent the thought that the tree is empty now but it will have fruit again at some point in the future. Hoerl & McCormack suggest that humans (and only humans) are a species of temporal reasoning, which is why they are capable of mental temporal representations concerning points in time (past or future) that goes beyond the immediate now.

There is anecdotal evidence that great apes can represent a temporal point in the future that is distinct from now. Osvath (2009) reports of a male chimpanzee named Santino in Furuvik Zoo, Sweden, who has been observed to gather stones and pieces of concrete in the morning hours before the zoo is open and place them at the shoreline facing the public observation area for later use as projectiles against people. The gathering of the ammunition, during which the chimpanzee is observed to be in a calm state, appears to be in anticipation of the future state of visitor arrival given that stones and pieces of concrete are never used in contexts other than throwing at zoo visitors and the relevant behavior is not displayed off–season when the zoo is closed to visitors. This behavior "is clearly identifiable as planning for a future state" (Osvath, 2009, p. 191), the state at which a crowd of people gather at the visitors' area neighboring the island enclosing the chimpanzee, which is distinct from the preparation state in which there are no visitors at all. We take this as evidence that the chimpanzee Santino can mentally represent a future situation that is distinct from the current situation, which contradicts the claim that non-human animals are restricted to temporal update.

There is also experimental evidence for future-oriented tool use in great apes. Mulcahy and Call (2006) tested the capacity of bonobos and orangutans to save tools for future use with or without visual access to the reward. In one experiment, the apes first learnt to use a plastic tube to retrieve the grapes inside a cylinder. They were then presented with eight tools, only two of which were functional for the task at hand. During the selection period (5 min.), the reward was visible but rendered inaccessible by a transparent Plexiglas barrier. After selecting one of the tools, the apes were ushered away from the test room into a waiting room, where they would have to stay for one hour before they could re-enter the test room to collect the reward with the tool they had transferred to the waiting room. In 70% of the trials, the apes carried tools to the waiting room, and they returned to the test room with the suitable tools more often than expected by chance. In another experiment, the apes first learnt to use a hook to obtain a juice bottle suspended from a rope. Unlike the previous experiment, there was no visual access to the apparatus containing the reward during the selection (5 min.) and the waiting period (1 hour). Once the apes were back in the test room, the apparatus containing the reward was installed and they could obtain the reward if they had selected and transferred the hook to the waiting room in the first phase of the experiment and returned with it to the test room in the last phase. The apes transported the appropriate tool to the waiting room above chance level and they returned the suitable tool to the test room more often than other tools, but this time the difference was not statistically significant. Mulcahy and Call (2006, p. 1039) suggest that these experiments provide evidence for "a genuine case of future planning" in apes. Osvath & Osvath (2008) replicated the latter experiment, this time with fruit soup inside a wooden box as the reward and a straw to be used for extracting the fruit soup as the functional tool. In this experiment, the apes selected tools in a separate location than the test room so that there would no visible cue for the presence of the reward. Of the three apes tested, two selected the functional tool in all 14 trials and retrieved the reward in 11 of these. The other ape selected the right tool in 13 out of 14 trials and obtained the reward in 12. Observe that all the experiments described above have an initial learning phase during which the apes have some (positive) experience with the tool they are expected to choose in the trials. It could, then, be argued that the apes form a positive association between the functional tools and the reward, which is why they pick the tools that they do in the experiments, rather than envisioning a role for these tools in a future plan. To eliminate this possibility, Osvath & Osvath (2008) ran another experiment in which the apes were presented with four tools, three of which were novel (hence, no associational learning involving them) and the successful completion of the task required that they choose one of these novel tools rather than the familiar one. The apes selected the functional (as opposed to the familiar) tool in 11/12, 10/12 and 9/12 trials respectively. This suggests that the apes did attend to the functional details of the objects presented to them, going beyond what might be expected from simple associative learning.

It is not clear that these experiments should be taken as evidence for attributing apes a mental representation of a future state of affairs distinct from now (Suddendorf, 2006; Suddendorf et al., 2009). Suddendorf et al. (2009, p. 752) note that the study by Osvath and Osvath (2008) "describes no future-directed attempts by the animals to guard the straw from conspecifics during the delay period", which would be expected if the apes had the mental representation of the future availability of the food. Similarly, Roberts & Feeney (2009, p. 275) claim that Osvath and Osvath's apes might have chosen the straw "because they knew its functional value for sucking up fruit soup without anticipating its use 70 mins in the future" (in this experiment, the waiting time was 70 minutes). Selecting a tool for some reward and sticking to it for some time may be understood to be consequences of a mental state of the form 'available(food, now)' and the desire to obtain this food. We need not, it seems, attribute the apes under test a future-oriented thought of the form 'available(food, t) & now < t'. At least, it is not clear that we should. In the first experiment of Mulcahy and Call, in which the apes could see the reward throughout the experiment, one may think that the visual access to the reward was the cue for the current availability of the food. In the experiments where the visual access to the apparatus involving the reward was blocked, one may think that the apes did not take the absence of evidence for the reward as evidence for the absence of the reward, an example of the capacity for displaced reference, which apes apparently have (Woodruff & Premack, 1979; Lyn et al. 2014 among others).

There is some clearer experimental evidence for future-directed behavior among apes. An orangutan by the name of Riau was observed to spontaneously secure a large tool for future use by wedging it into gaps of the fence of his 238 m^2 enclosure (Mulcahy, 2018). Mulcahy experimentally tested the hypothesis that the ape exhibited this behavior in response to the future availability of food. In one experiment, a lidless container with 12 food items (apples and oranges) was positioned outside of Riau's enclosure but within his full view. In each trial, the experimenter placed two of these food items inside a metal ring and then put the ring on a wooden testing table attached to the outside of the fence. Riau had to use a long stick that he fashioned earlier to rake-in the food in the out-of-reach ring. The experiment in each day consisted of six consecutive trials with one minute of waiting time between them and Riau was expected to hang up the tool on the narrow gaps in the fence at the end of five of these trials in which there was food left in the container for later consumption (Hang-up Tool trials) and discard the tool in the last trial in which he could see that the container was empty and there was no future use for the stick (Discard Tool trials). After twelve days of experimentation, Mulcahy (2018, p. 2) found that Riau secured the tool "in 98% (59/60) of Hang-up Tool trials in which he could predict its future-use for raking-in forthcoming rewards. By contrast, there was a low frequency of observed large tool securing (8%, 1/12) in the Discard Tool trials".[3] While selecting

[3] In a second experiment, Mulcahy (2018) tested the hypothesis that Riau hung up this tool becaseu of its large size and heavy weight as carrying it back to the testing area would be difficult once it is dropped. Indeed, when given a

a tool among a set of options is a type of behavior triggered by the current availability of the reward, hanging up a tool precisely when there is more reward to be retrieved appears to be the kind of behavior directed towards the future availability of food, which can be taken as evidence that Riau is capable of a future-oriented temporal thought of the form ‘available(food, t) & now < t’ and act accordingly.

To say that apes are capable of temporal thoughts is not to say that any kind of temporal thought is available to them. Riau’s behavior was directed towards a very near future and evidence for this future state of affairs was already available in the current state of affairs (i.e. the food items in the container). The stone-throwing chimpanzee Santino we have discussed above has also been observed to hide stones under heaps of hay so that visitors cannot back away in time at the release of the projectiles (Osvath & Karvonen, 2012). This future-oriented hiding behavior seems to be initiated by the presence of visitors in the environment: “Both the manufacture and use of the concealments were likely premediated. The behavior never occurred when anyone was within the chimpanzee’s view, but only after a group had been present and left: i.e., prior to their possible return. That is, it appears to have been prompted by the prior presence of visitors on those days when it occurred: the chimpanzee prepared no concealments on days when he had not previously seen visitors.” (Osvath & Karvonen, 2012, p. 6) We suggest that the temporal thoughts underlying these types of behaviors can be expressed within a referential theory of tense amended with the SOON function controlling the output of the assignment function g. The assignment function g maps free variables to temporal intervals, in this case to the output of the SOON function, which takes the contextual parameter *now* as input and gives an interval that counts as soon considering the immediate now. This idea can be expressed formally as follows:

(12) The temporal thought underlying Riau’s tool securing behavior

available(food, t) & now < t

with g(t) = SOON(now)

smaller and lighter tool to retrive a reward, Riau did not secure this tool even at trials in which he could anticipate further use for it.

(13) The temporal thought underlying Santino's stone hiding behavior

gather(people, t) & now < t

with g(t) = SOON(now)

It is possible to make use of the SOON function to anticipate a future state of affairs so long as it is evidenced by the current state of affairs. This, however, fails to account for the stone collecting behavior of Santino hours before there are any visitors in the zoo. Crucially, unlike the stone hiding behavior which was observed in the pre-season during which visitors arrived at irregular intervals and several days apart, the stone collecting behavior happened during the general reason when visitors arrived every day (Osvath & Karvonen 2012). We might imagine that this behavior was directed towards a specific period of the day in which the event was expected to happen (for concreteness, we represent periods of the day as MORNING, NOON, EVENING and NIGHT but it is likely that animals make more granular distinctions: EARLY_MORNING, MID_MORNING, LATE_MORNING etc.). Indeed, Campbell (1996, p. 117) notes that "an animal which has a circadian clock may use it to identify the time at which food appears at a particular place. For example, on encountering food at a particular place at noon, the animal may form the hypothesis that in general there will be food at that place at noon, so that at subsequent noons it expects food to be at that place." Given the regularity of visits during the general season, it is likely that Santino has associated a period of the day (say, NOON) with visitors' arrival. We assume that periods of the day can function as the output of the assignment function g.

(14) The temporal thought underlying Santino's stone collecting behavior in the morning

gather(people, t) & now < t

with g(t) = NOON

This means that future-oriented thought in apes is either restricted to temporal intervals that are expected to come soon given a current state of affairs or oriented towards the next relevant period of the day. What about temporal thoughts about past? There is experimental evidence that apes are capable of recalling past events after very long delays provided that the environment of recall contains sufficient distinctive cues overlapping with the past experience. Martin-Ordas et al. (2013) show that when facing the same task with the same experimenter in the same location, apes successfully retrieved the details of a tool hiding event from three years ago, as evidenced by the fact that they searched for the relevant tool precisely where it was hidden (see Lewis et al., 2019 for further discussion of long-term past memory in apes). Given these findings, we shall assume that the assignment function *g* can, in principle, deliver any temporal interval in the past that the animal in question has experienced.

Below, we provide a temporal grammar for non-human apes that defines/generates expressions of the kind we have seen in (12), (13) and (14). We suggest that such a grammar contains temporal variables but no operations that involve variable-binding, which is why it is an example of a referential tense system rather than a quantificational tense system.[4] Let X be a standard predicate of arity n, then X' is the temporal rendering of the predicate X of arity n+1, where X' differs from X only in the addition of a temporal variable as its last argument. For instance, the predicate *like* of arity 2, where "like(x, y)" means x likes y, has the temporal rendering *like'* of arity 3, where "like'(x, y, t)" means x likes y within the interval t. If a predicate contains a temporal variable as one of its arguments, we shall call it a temporal predicate.

(15) Temporal Ape Grammar

Rule 1. If "P" is a temporal predicate of arity n,

"x_1", "x_2", … "x_{n-1}" are individual variables

and "t" is a temporal variable,

then "P(x_1, … x_{n-1}, t)" is a sentence.

Rule 2. If "t_1" and "t_2" are temporal variables or *now*

then "$t_1 < t_2$" and "$t_1 = t_2$" are sentences.

Rule 3. If "φ" and "ψ" are sentences

then so are "$\neg\varphi$", "φ & ψ", "$\varphi \rightarrow \psi$" etc.

---

[4] We shall argue, in the next section, that only humans are capable of temporal thoughts involving variable binding, which enables them to transcend the limitations of a referential tense system. See Bolender (2016) and Bolender et al. (2008) for cognitive consequences of variable-binding in the context of variables for individuals.

As we have discussed in this section, there are many distinct temporal thoughts that can be expressed within this grammar. As it happens, there are also many temporal thoughts that a grammar of this kind is unable to represent. This is the topic of the next section.

3. Temporal Quantification in Humans

Suddendorf (2006, p. 1006) writes: “What is in your pocket? Chances are you carry keys, money, cosmetics, a Swiss Army knife, or other tools – because they may be useful at some future point.” The phrase that deserves underlining in this quote is “at some future point”. Unlike non-human primates whose temporal thoughts are restricted to a past of experiences and to a future cued by the current state of affairs or limited to periods of the day, human temporal thought does not seem to be constrained by the contingencies of the assignment function, which, we suggest, makes humans capable of thoughts concerning an event taking place at some unspecific interval in the past or in the future.[5] In this section, we focus on the linguistic underpinnings of this temporal capacity.

How do humans transcend the limitations of Temporal Ape Grammar? In a referential tense system, the scope of temporal thoughts is determined by what the assignment function can deliver. Therefore, it must be that humans are capable of thoughts that are independent of the assignment function. Recall that the assignment function takes free variables as input. Then, it must be that humans can mentally represent temporal sentences in which there are no free variables, i.e. sentences in which the variables are bound by operators. We have already seen an example of such a sentence in the context of the existential past tense in Javanese. As another example, consider the sentence in (16), which loosely corresponds to the English sentence “John has danced or will dance at some point”

(16) $\exists t.\ \text{dance}(\text{John}, t)$

In (16), the embedded sentence “dance(John, t)” contains a temporal variable. This temporal variable is bound by the existential quantifier scoping over the embedded sentence. In formal logic, the assignment-independent nature of such sentences is captured by saying that while the formula “$\exists t.\ \text{dance}(\text{John}, t)$” is evaluated with respect to an arbitrary assignment function g, the

[5] Indeed, we are so occupied with what has happened in the past or what the future may hold for us that we are frequently accused of losing the moment, with slogans such as “Carpe diem!”.

open[6] sentence "dance(John, t)" is evaluated with respect to the assignment function $g[t \rightarrow i]$, where $g[t \rightarrow i]$ is just like g with the possible exception that it assigns the interval that is quantified over to the variable t. More specifically, a quick calculation of the truth conditions of (16) goes as follows:

(17) "$\exists$t. dance(John, t)" is true with respect to g if and only if

there is an interval i such that "dance(John, t)" is true with respect to $g[t \rightarrow i]$,

that is, "$\exists$t. dance(John, t)" is true with respect to g if and only if

there is an interval i such that John dances within i.

Observe that the assignment function g we happen to choose has no bearing on the content of the sentence in (16). Let g_1 and g_2 be two distinct assignment functions with respect to which the sentence "$\exists$t. dance(John, t)" is to be evaluated. Then, the open sentence "dance(John, t)" gets to be evaluated with respect to $g_1[t \rightarrow i]$ or $g_2[t \rightarrow i]$. In either case, the free variable t in this open sentence gets the same value, meaning that the assignment function plays no role in how "$\exists$t. dance(John, t)" is associated with meaning. In other words, for any assignment functions g_1 and g_2,

(18) "$\exists$t. dance(John, t)" is true with respect to g_1 if and only if

"$\exists$t. dance(John, t)" is true with respect to g_2

That is, unlike other primates, humans can mentally represent temporal thoughts that are free of the contingencies of this or that assignment function.

Let us take a closer look at how binding of temporal variables is achieved in human grammar. In standard temporal logic, a formula of which is given in (16), we find that there is a one-to-one relation between quantification and variable-binding in that it is via quantifiers that variables are bound. This is not, however, how variable-binding seems to work in natural language grammar, where variable binding is dissociated from quantification due to the grammatical rule of Lambda Abstraction. The lambda operator (also written as the λ-operator) introduced by this rule is responsible for binding variables without inducing quantification over their denotations. Instead,

[6] A sentence is said to be open if it contains a free variable.

the outputs of the rule of Lambda Abstraction function as input to the rules of quantification (see Heim & Kratzer, 1998, Section 7.4.1 for an explicit discussion of the dissociation between variable-binding and quantification in formal semantics). To see how this idea works in the context of variables for individuals, consider first the logical translation of the sentence "Sue likes him." in (19). To determine the truth conditions of this sentence, we need to find out whom "him" refers to. That is, the content of this sentence depends on what the assignment function assigns to the free variable associated with the pronoun "him". Suppose that Sue likes Bill but not John. Then, this sentence is true with respect to any assignment function which outputs Bill as the individual referred by the variable x, a condition satisfied by g_1 below but not g_2.

(19) like(Sue, x)

g_1: {<x, Bill>, <y, John>, …}, g_2: {<x, John>, <y, Bill>, …}

"Sue likes him" is true with respect to g_1 but not with respect to g_2.

When the relative pronoun "whom" is used instead of the personal pronoun "him", we obtain a relative clause that involves movement of the relative pronoun to the clause-initial position as in (20a), an operation known as operator movement (Chomsky, 1977). In (20b), the relative clause constructed after this movement operation functions as the modifier of the noun "man".

(20) a. [whom$_1$ [Sue likes t_1]]

b. … the [[man] [whom Sue likes]]

The relative clause in (20a) denotes a property, the property of being liked by Sue. How exactly does the relative clause in (20a) end up denoting a property? This is made possible by a rule responsible for binding variables with the help of the lambda operator, the operator symbolized with "λ" below. This rule, known as Lambda Abstraction, takes an open sentence as input and gives a property that is characterized by this sentence.

(21) Rule 4. Lambda Abstraction

If φ is a sentence with the free variable x, i.e. $\varphi[x]$, then $\lambda x.\ \varphi[x]$ is a lambda term.

In (20a), the operator movement of the relative pronoun leaves a trace in its initial position ("t_1" in "[Sue likes t_1]"), which is interpreted as a free variable at the level of logical form as in (22):

(22) like(Sue, x)

This open sentence can now function as input to the rule of Lambda Abstraction. We can say that the net effect of the movement of the relative pronoun in syntax as in (20a) is the application of this rule at the level of Logical Form (Heim & Kratzer, 1998), as a result of which the free variable in (22) is now bound by the lambda operator.

(23) λx. like(Sue, x)

Formally, the lambda term in (23) corresponds to a function from the domain of entities D_e to truth values. That is, the lambda term is formally equivalent to the function f, where:

(24) f: $D_e \rightarrow \{0,1\}$

f(x) = 1 if and only if Sue likes x

This function in (24), as well as the lambda term in (23), characterizes the set of individuals liked by Sue, i.e. the set in (25).

(25) $\{x \in D_e$: Sue likes x$\}$

This set includes all and only the individuals that Sue likes. It other words, it is the meaning of the property of being liked by Sue. The rule of Lambda Abstraction is responsible for generating properties out of open sentences.

Similar to the personal relative pronoun “whom”, the temporal relative pronoun “when” can be used to construct a relative clause as in (26a) modifying a temporal noun such as “night” in (26b). In such structures, too, we find that this relative pronoun undergoes operator movement to the clause-initial position.

(26) a. [when$_1$ [John danced t_1]]

b. … the [[night] [when John danced]]

The logical form of the sentence “[John danced t_1]” is shown in (27), where the trace is replaced by the temporal variable t.

(27) t < now & dance(John, t)

We have noted that the operator movement in syntax results in the application of the rule of Lambda Abstraction at the level of Logical Form. As such, the lambda operator ends up binding both of the free variables in (27), resulting in (28) as the logical form of (26a).

(28) $\lambda t.\ t < now\ \&\ dance(John, t)$

This is a temporal predicate, one that characterizes the set of intervals before the speech time at which John danced.

(29) $\{t \in D_t: t < now\ \&\ dance(John, t)\}$

When we combine the temporal noun "night", which, we assume, denotes the set of intervals that correspond to what people call the night time, perhaps [9pm, 4 am], for each day, i.e. $\lambda t.\ night(t)$, with the temporal predicate "when John danced", we end up creating a new predicate which can be thought of as the logical translation of the natural language expression "night when John danced"

(30) $\lambda t.\ night(t)\ \&\ t < now\ \&\ dance(John, t)$

The logical form associated with the sentence obtained by prefixing the expression "there was a" to the nominal phrase "night when John danced", whose logical form we have seen in (30), is shown in (31). Following much work since Frege (1879), we take quantification to be a second-order operation over predicates. Quantifiers take lambda terms such as (30) as input and generate sentences that make assertions about sets denoted by these predicates. Ultimately, the sentence in (31) says that the set characterized by the lambda term in (30) is not empty.

(31) English sentence: There was a night when John danced.

Logical Form: $\exists(\lambda t.\ night(t)\ \&\ t < now\ \&\ dance(John, t))$

Meaning: $\{t: night(t)\ \&\ t < now\ \&\ dance(John, t)\} \neq \emptyset$

We are now in position to define a temporal grammar for humans on the basis of Temporal Ape Grammar we have seen at the end of Section 2. Let P a temporal lambda term, ultimately a function from temporal intervals to truth values. Then P*, the set characterized by P, is the set of intervals at which P holds (i.e. $P^* = \{t: P(t)\}$). In this system quantification is captured via the existential "∃" and the universal "∀" quantifiers, each of which takes a lambda term as argument and generates a sentence as output, which we take to be a proxy for temporal thoughts.

(32) Temporal Human Grammar

contains *Temporal Ape Grammar* and *Lambda Abstraction* and the following rules:

Rule 5. If "P" is a temporal lambda term and "t" is a temporal variable,

then "P(t)" is a sentence meaning $t \in P^*$.

Rule 6. If "P" is a lambda term, then "∃(P)" is a sentence meaning $P^* \neq \emptyset$

Rule 7. If "P" is a lambda term,

then "∀(P)" is a sentence meaning $P^* = D_t$, the set of all intervals.

We have not seen any examples of universal quantification over temporal intervals in this paper. This mode of quantification is operative in sentences such as "When you eat Chinese food, you are always hungry an hour later" (an example from Partee, 1973: 606) or "John always smiles /John smiles all the time":

(33) a. $\forall(\lambda t.\ \text{eat}(x, \text{Chinese food}, t) \rightarrow \text{hungry}(x, \text{one\_hour\_later}(t)))$

b. $\forall(\lambda t.\ \text{smile}(\text{John}, t))$

The sentence "John always smiles" is not typically taken to mean that John constantly smiles throughout his days. Rather, it seems to mean something like pretty much every time he might be expected to smile, John smiles at that moment. That is, quantification over temporal intervals is restricted implicitly to a set of temporal intervals that are somehow understood to be relevant. This is not surprising. When a sentence such as "Every bottle is empty" is uttered in a conversation, we do not usually conclude that every single bottle in the universe is empty. Rather, we understand that the bottles in some contextually restricted set (the ones in the room, the ones we bought last week etc.) are empty (Stanley & Szabó, 2000). That is to say, quantification is typically understood to be implicitly restricted by the context and temporal quantification is no exception.[7]

Temporal Human Grammar is a grammar of both continuity and discontinuity. Continuity should be apparent in the fact that Temporal Human Grammar properly contains Temporal Ape Grammar, which means that an expression of Temporal Ape Grammar is also an expression of Temporal Human Grammar. There are, however, expressions of Temporal Human Grammar, specifically those involving variable-binding and quantification, whose structure cannot be represented in Temporal Ape Grammar. Indeed, it is precisely the involvement of these rules in defining linguistic expressions that makes some temporal thoughts uniquely human. In the next section, we shall explore how Temporal Human Grammar might account for the human ability refer to unique intervals that one cannot access via the assignment function.

4. Cognition by Temporal Description

In this section, we shall argue that Temporal Human Grammar gives rise to a new type of specificity about temporal intervals, one that involves referring to unique intervals that go beyond what the assignment function can deliver. We call this capacity Cognition by Temporal Description adapting a term from Bolender (2016), who, in turn, builds on ideas from Bertrand Russell's epistemology.

Russell (1905, 1911) distinguishes between two modes of knowing things: knowledge by acquaintance and knowledge by description. We know something by acquaintance if our knowledge of it is obtained by directly perceiving it. This kind of knowledge does not involve any mediation of linguistic representations or symbolic thought processes. We know something by description if we know that some description, in the form of a predicate, uniquely applies to it, which requires use of logical forms expressing quantificational thoughts. Our knowledge of the author of Sir Gawain and the Green Knight, who remains unknown to this day, is of this nature. Knowledge by description is a way of knowing things that we have no direct contact with. Russell suggests that sentences involving definite descriptions are crucially involved in this mode of knowing, where definite descriptions are typically, but not necessarily, expressions of the form "the F". For Russell (1905), sentences involving definite descriptions have multiclausal logical

[7] We do not wish to suggest that Temporal Human Grammar encompasses all the complexity of human temporal thoughts. Our main claim is that this grammar characterizes a significant aspect of human temporal capabilities.

forms. For instance, the sentence "The author of Sir Gawain and the Green Night lived in Western England" makes claims of existence (i.e. there is at least one author of Sir Gawain and the Green Night) and exhaustivity (i.e. there is at most one author of Sir Gawain and the Green Nights), which leads to uniqueness (i.e. there is exactly one author of Sir Gawain and the Green Knight), expressible with the quantifier "∃!", which can be read as "there is exactly one…".[8] The sentence says, moreover, that whoever this individual is, they lived in Western English.

(34) $\exists!(\lambda x.\ \text{author}(x, \text{Sir Gawain and the Green Night}))$ &

$\forall(\lambda x\ \ \text{author}(x, \text{Sir Gawain and the Green Night}) \rightarrow \text{lived}(x, \text{Western England}))$

Russell's project is about foundations for our knowledge of the world, a project within epistemology. We are not, however, interested in whether a sentence involving a definite description is true, a precondition for it to count as knowledge, nor are we interested in what would be involved in deciding that it is true, its justification. Rather, we wish to understand what kind of mental capacity is involved in mentally representing thoughts about entities that are not within our experiential domain – irrespective of whether such a thought describes the world accurately or not. To eliminate this normative aspect of Russell's project, Bolender (2016) proposes the term *Cognition by Description* for the capacity to mentally represent an entity that one has not been in direct contact with. This capacity, as we have seen, makes use of quantificational logical forms. Bolender suggests that Cognition by Description is a uniquely human capacity due to the fact that humans and only humans can mentally represent quantificational structures, a claim that we have adopted in this paper.

It is worth noting that definite descriptions are not always about individuals. There are also temporal definite descriptions that can be used to refer to unique intervals in the past or in the future.

(35) a. … the night (when) John met Sue

b. … the night (when) John will meet Sue

[8] This is really just shorthand for the formula:
$\exists(\lambda x.[\text{author}(x, \text{Sir Gawain and the Green Night})\ \&\ \neg(\exists(\lambda y.\ \text{author}(y, \text{Sir Gawain and the Green Knight})\ \&\ x \neq y))])$

When the definite description in (35a) is used in a sentence, we understand that there was a unique night preceding the utterance time within which John met Sue. This claim of uniqueness can be represented as in (36):

(36) $\exists!(\lambda t.\ night(t)\ \&\ t < now\ \&\ meet(John, Sue, t))$

We can, then, say of this unique interval that Mary met Bill within the same interval. In other words, the logical form of the sentence "Mary met Bill the night John met Sue" would involve the conjunction of (36) and (37).

(37) $\forall(\lambda t.\ night(t)\ \&\ t < now\ \&\ meet(John, Sue, t\ ) \rightarrow meet(Mary, Bill, t))$

In this way, we can represent unique intervals in the past we have no memory of (36) and make assertions about these intervals (37). We can also represent thoughts involving unique intervals in the future that are neither cued by the present state of affair nor oriented toward periods of the day. We can, for instance, represent the thought that there will be a unique night within which John meets Sue. Since the content of such a thought is independent of the assignment function, it is not constrained by what this function can deliver.

(38) $\exists!(\lambda t.\ night(t)\ \&\ now < t\ \&\ meet(John, Sue, t))$

Adapting Bolender's terminology, we shall call this capacity *Cognition by Temporal Description*. We suggest that Temporal Human Grammar, which defines quantificational logical forms involving temporal variables, is what enables this capacity.

Temporal definite descriptions may turn out to be more pervasive in natural languages than previous thought. In a recent paper, Zhao (2023) argues that the simple past tense in English should be analyzed as a definite description. That is because, if past in English were a purely referential category, we would expect sentences in the past tense to refer to contextually salient intervals. That is, their distribution would be similar to that of pronouns, which cannot be used without a salient antecedent. ("He lives in Reykjavik" sounds strange unless the antecedent of "he" is retrievable from the context.) However, there are cases where a past sentence can be used in the absence of any contextually salient time interval. Consider the following exchange from Kratzer (1998):

(39) A: Who built this church?

B: Borromini built this church.

For this exchange to be felicitous, it is not necessary for there to be a salient interval within which the church was built. All that is needed is for there to be some interval in the past at which the church was built. One way to deal with the felicity of these sentences would be to say that the past tense in English is, indeed, an existential quantifier over temporal intervals (Ogihara, 1996). The sentence presupposes that there was some interval in the past in which the church was built and asks who the agent of this event is. However, this approach faces two main problems. First, it does not provide an explanation for the systematic differences between the past tense in English and the past tense in Javanese. Recall from Section 1 that the acceptability judgments associated with past sentences in Javanese, which is purely existential, differs systematically from what we find in English. Second, a purely existential analysis appears to be empirically problematic. Matthewson et al. (2019) ask us to consider a scenario in which a group of people are walking in the woods and they find a piece of litter on the ground. Then, one of them asks:

(40) Who littered?

While (40) is a fine question in the context just described, if we wish to inquire about who has done some littering at some point in their lives, (40) would be a strange way of doing that. However, if past in English is purely existential, then the question in (40) is expected to be felicitous in this context. Rather, (40) seems to be presuppose a unique interval within which someone littered, implicated by the presence of that piece of litter on the ground, and asks about the agent of the event that took place in this unique interval. Starting with these observations, Zhao argues that this set of data can be explained on the assumption that past in English is a temporal definite description. In asking the question in (39), for instance, we presuppose a unique interval within which the church was built. Since tense, under this analysis, is not a referential category, it is not necessary that this interval be contextually salient. The uniqueness claim associated with the sentences in (39) can be expressed as follows.

(41) $\exists!(\lambda t.\ t < now \ \&\ is\_built(the\ church, t))$

Asking the question in (39) is then asking for the unique individual x such that in the unique interval within which the church was built, it was x who built the church.

(42) I want to know the unique x such that

$$\forall(\lambda t.\ [t < now\ \&\ is\_built(\text{the church}, t) \rightarrow build(x, \text{the church}, t)])$$

If the simple past tense is, indeed, like a temporal definite description, then Cognition by Temporal Description is operative even in simple past sentences. That is, it has a wider role in organizing human temporal thoughts than previously believed. Indeed, in the next section, we suggest that Cognition by Description may have some role to play in enabling (or at least boosting) the capacity for *Mental Time Travel*.

5. A note on Mental Time Travel

Mental Time Travel is the capacity of humans "to mentally project themselves backwards in time to re-live, or forwards to pre-live, events" (Suddendorf & Corballis, 2007, p. 299). In this section, we discuss the role that a quantificational temporal grammar might have played in this capacity.

There is a distinction to be made between knowing that an event happened and remembering this event happening (Tulving, 1972; 1983). We know when we were born without remembering the event of our birth. The date of our birth is the kind of information that is stored in semantic memory, which involves symbolic representations such as concepts, relations between concepts and propositions, some of which characterize our explicit knowledge of the world. Semantic memory forms the basis of our capacity for symbolic reasoning. This memory is to be distinguished from episodic memory, which is a memory of autobiographical experiences. Units of episodic memory can, at times, be retrieved in the form of re-living a past event, say as the personal memory of kissing our first partner for the first time. Semantic and episodic memory are categorized as declarative due to the fact that we seem to have (at least partial) conscious access to them, thanks to which we can verbalize their content to some extent.

The capacity for Mental Time Travel relies on episodic memory in that they both involve the experience of living through events. However, this capacity goes beyond what has happened to an individual in the past in that it makes use of the continuum from past to future: "Mental Time Travel allows us to imagine events at different points in this continuum, even at points prior to birth or after death. This means that mental time travel is a generative process, incorporating known elements but arranged in particular ways to create the experience of events that are actually occurring." (Suddendorf & Corballis, 2007, p. 301). Let us take a closer look at the concepts of "points prior to birth" and "points after death". The temporal intervals before birth, which can be taken to be the meaning of the linguistic expression "before I was born", cannot be accessed via episodic memory as we may have no experiential memory of the unique interval at which we were born or the intervals that preceded it. Moreover, Temporal Ape Grammar has no means to represent and make use of such a concept given that free temporal variables in this grammar can only refer to a past of experiences. Interestingly, this concept can be expressed in Temporal Human Grammar. First, we represent the unique interval of our birth.

(43) $\exists!(\lambda t_1.\ \text{is\_born}(\text{the speaker}, t_1))$

We can, then, represent the lambda term corresponding to the temporal concept of the intervals preceding our birth.

(44) $\lambda t_2.\ \exists!(\lambda t_1.\ t_2 < t_1\ \&\ \text{is\_born}(\text{the speaker}, t_1))$

Similarly, projecting oneself onto a future point requires access to future intervals of the kind generated by a quantificational temporal grammar. If we want to think about what happens after we die, we must first generate the concept of the temporal intervals after our death, which we take to be the concept expressed by "after I die":

(45) $\lambda t_2.\ \exists!(\lambda t_1.\ t_1 < t_2\ \&\ \text{die}(\text{the speaker}, t_1))$

Mental Time Travel seems to be making use of the type of concepts that Temporal Human Grammar generates. This is unlikely to be accidental. It seems that this capacity relies on Temporal Human Grammar, and Cognition by Description supported by this grammar, to construct temporal intervals in the past and in the future. It is also worth noting that Mental Time Travel has a property that is typically associated with natural languages: productivity. "Like human language, it is open-ended and generative, so there is no end to the number of potential future scenarios one might envisage." (Suddendorf & Corballis, 2007, p. 302).

How does Temporal Human Grammar enter into Mental Time Travel? The outputs of Temporal Human Grammar are lambda terms and sentences. Semantically, these correspond to concepts and propositional thoughts. Such mental objects are stored in semantic memory. Then, it seems that Mental Time Travel relies both on episodic memory and on semantic memory boosted by a quantificational grammar. There is much evidence suggesting involvement of semantic memory in Mental Time Travel (Hodges & Patterson, 2007; Irish et al., 2012; Irish & Piguet, 2013). Indeed, building on the research just cited, Irish (2016, p. 401) proposes the Semantic Scaffolding Hypothesis, according to which

> "[S]emantic knowledge provides the requisite framework that enables (re)construction of the past and simulation of the future. Thus when we attempt to project forward in subjective time, we invoke a representative semantic schema or foundation to provide the necessary structure and meaning to the overall event … Once this broad framework is in place, relevant sensory-perceptual details from episodic and semantic memory can then be harnessed and assimilated into the schema."

Perhaps the strongest evidence for the involvement of semantic memory in Mental Time Travel comes from patients with the neurodegerative disorder of Semantic Dementia (Hodges & Petterson, 2007; Irish et al., 2012). A noted feature of this syndrome, which is associated with loss of conceptual knowledge, is anomia, the inability to name objects or concepts (Hodges & Petterson, 2007). While the episodic memory of such patients remain largely intact so long as the episodic recall does not rely on verbal tasks (Maguire et al., 2010), their capacity for mental time travel to a future point is severely compromised (Duval et al., 2012; Irish et al., 2012). This suggests that the capacity for Mental Time Travel is contingent on a functioning semantic memory boosted by a quantificational grammar.

An event of experience in the past, say the cloudy night in which someone kissed their partner, can be stored in two ways: as an autobiographical experience in episodic memory and as a temporal concept in semantic memory. In semantic memory, this would take the form of the temporal concept of the "cloudy night in which I kissed my partner", which would have the form shown in (46).

(46) $\lambda t.\ \text{night}(t)\ \&\ \text{cloudy}(\text{the sky}, t)\ \&\ t < \text{now}\ \&\ \text{kiss}(\text{the speaker}, \text{the partner}, t)$

Deacon (1997) notes that such symbolization is "a way of offloading redundant details from working memory, by recognizing a higher order regularity in the mess of associations, a trick that can accomplish the same task without having to hold all the details in mind" (p. 89). Storing the symbolic representation of an event in semantic memory is cheaper than storing the sequence of stimuli constituting the event in episodic memory. Moreover, it is likely that symbolic memories are easier to manipulate as well. By deleting the sentence “cloudy(the sky, t)” from the representation in (46), we lose some information about the weather conditions during the kiss. By the addition of the sentence “starry(the sky, t)”, the kiss becomes part of a starry night that is more conducive to romance. One may even start believing that they kissed their partner in a starry night of the kind we find in van Gogh paintings. Once a temporal interval is stored in semantic memory as a symbolic representation, all kinds of deletions, additions and distortions become easier to employ. It should not surprise us, then, that people are not very successful at remembering the past events the way they actually happened (Loftus, 1979/1996). Since symbolic temporal concepts are enabled by Temporal Human Grammar, we can say that developing a completely distorted picture of our past is also a unique human attribute.

6. Conclusion

Thought has structure. Structures can be compared with respect to the complexity of grammars that define them. In this paper, we took advantage of logical grammars in measuring the complexity of temporal thoughts in apes and in humans. We saw that the logic characterizing temporal thoughts in humans is strictly stronger than the logic characterizing temporal thoughts in apes. This approach leads to a view of language evolution as transition between logics. Thus, one way of thinking about language evolution is asking what kind of transition between logics could explain both the similarities and the differences between (non-human) ape thought and human thought. Putting this idea in more general terms, we may propose the following research project: Given a hierarchy of logics of interest, find the weakest logic that can express the structure of (non-human) primate thought, find the weakest logic that can express the structure of human thought and ask what is involved in the transition between them. In our case, we highlighted the role of variable-binding and quantification in this transition. If we agree that the complexity of human thought is indicative of the complexity of the logical grammar that the human mind can manipulate, then this research project is expected to deliver insightful results on how grammar transforms the thought systems with which it interacts.

REFERENCES

Bolender, J. (2016). Cognition by description. *Filosofia Unisinos – Unisinos Journal of Philosophy,* 17(2), 136 – 143. https://doi.org/10.4013/fsu.2016.172.07

Bolender, J., Erdeniz, B., & Kerimoğlu, C. (2008). Human uniqueness, cognition by description, and procedural memory. *Biolinguistics,* 2(2-3), 129 - 151. https://doi.org/10.5964/bioling.8637

Campbell, J. (1996). Human vs. Animal Time. In M. A. Pastor & J. Artieda (Eds.) *Time, Internal Clocks and Movement*. (pp. 115 – 126). North-Holland.

Chen, S., Vander Klok, J., Matthewson, L. & Rullmann, H.. (2020). The 'experiential' as an existential past. *Natural Language & Linguistic Theory,* 1 – 50. http://doi.org/10.1007/s11049-020-09488-6

Chomsky, N. (1977). On wh-movement. In P. W. Culicover, T. Wasow, & A. Akmajian (Eds.), *Formal syntax* (pp. 71–132). Academic Press.

Deacon, T. (1997). *The symbolic species*. Penguin.

Duval, C., Desgranges, B., de La Sayette, V., Belliard, S., Eustache, F., & Piolino, P. (2012). What happens to personal identity when semantic knowledge degrades? A study of the self and autobiographical memory in semantic dementia. *Neuropsychologia*, 50(2), 254–265. http://doi.org/10.1016/j.neuropsychologia.2011.11.019

Frege, G. (1879). *Begriffsschrift*. Louis Nebert.

Grønn, A. & von Stechow, A. (2016). Tense. In M. Aloni, & P. Dekker (Eds.), *Handbook of formal semantics,* (pp. 313–341). Cambridge University Press. http://doi.org/10.1017/CBO9781139236157.012

Heim, I., & Kratzer, A. (1998). *Semantics in generative grammar*. Blackwell.

Hodges, J. R., & Patterson, K. (2007). Semantic dementia: a unique clinicopathological syndrome. *The Lancet Neurology,* 6(11), 1004–1014. http://doi.org/10.1016/S1474-4422(07)70266-1

Hoerl, C. & McCormack, T. (2019). Thinking in and about time: A dual systems perspective on temporal cognition. *Behavioral and Brain Sciences* 42 (e244):1-77. http://doi.org/10.1017/S0140525X18002157

Hornstein, N. (1993). *As Time Goes By: Tense and Universal Grammar.* The MIT Press.

Irish, M. (2016). Semantic memory as the essential scaffold for future-oriented mental time travel. In K. Michaelian, S. B. Klein, & K. K. Szpunar (Eds.), *Seeing the future: Theoretical perspectives on future-oriented mental time travel* (pp. 389–408). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780190241537.003.0019

Irish, M., Addis, D. R., Hodges, J. R., & Piguet, O. (2012). Considering the role of semantic memory in episodic future thinking: evidence from semantic dementia. *Brain*, 135, 2178–2191. http://doi.org/10.1093/brain/aws119

Irish, M., & Piguet, O. (2013). The pivotal role of semantic memory in remembering the past and imagining the future. *Frontiers in Behavioral Neuroscience*, 7, 27. http://doi.org/10.3389/fnbeh.2013.00027

Klein, W. (1994). *Time in Language*. London: Routledge.

Kratzer, A. (1998). More structural analogies between pronouns and tenses. In D. Strolovitch, & A. Lawson (Eds.), *Semantics and linguistic theory* 8. (pp. 92–110). http://doi.org/10.3765/salt.v8i0.2808

Lewis, A., Berntsen, D., & Call, J. (2019). Long-Term Memory of Past Events in Great Apes. *Current Directions in Psychological Science*, 28(2), 117 – 123. https://doi.org/10.1177/0963721418812781

Loftus, E.F. (1979). *Eyewitness Testimony*. Cambridge, MA: Harvard University Press. (Reissued with new preface in 1996).

Lyn, H., Russell, J. L., Leavens, D. A., Bard, K. A., Boysen, S. T., Schaeffer, J. A., & Hopkins, W. D. (2014). Apes communicate about absent and displaced objects: methodology matters. *Animal Cognition*, 17(1), 85-94. http://doi.org/10.1007/s10071-013-0640-0

Maguire, E. A., Kumaran, D., Hassabis, D., & Kopelman, M. D. (2010a). Autobiographical memory in semantic dementia: a longitudinal fMRI study. *Neuropsychologia*, 48(1), 123–136. http://doi.org/10.1016/j.neuropsychologia.2009.08.020

Martin-Ordas G., Berntsen D., Call J. (2013). Memory for distant past events in chimpanzees and orangutans. *Current Biology*, 23, 1438–1441 http://doi.org/10.1016/j.cub.2013.06.017

Matthewson, L., Cheni, S., Huijsmans, M., Morzycki, M., Reisinger, D. & Rullmann, H. (2019). Restricting the english past tense. *Snippets*. http://doi.org/10.7358/snip-2019-037-mchr

Mulcahy, N. J. (2018). An Orangutan Hangs Up a Tool for Future Use. *Sci Rep*. 27, 8(1), e12900. http://doi.org/10.1038/s41598-018-31331-7

Mulcahy, N. J., & Call , J. (2006). Apes save tools for future use. *Science*, 312, 1038 – 40. http://doi.org/10.1126/science.1125456

Ogihara, T. (1996). *Tense, attitudes, and scope*. Springer. https://doi. org/10.1007/978-94-015-8609-2.

Osvath, M. (2009). Spontaneous planning for future stone throwing by a male chimpanzee. *Current Biology*, 19, 190 – 1. https://doi.org/10.1016/j.cub.2009.01.010

Osvath M., & Karvonen, E. (2012). Spontaneous Innovation for Future Deception in a Male Chimpanzee. *PLoS ONE* 7(5), e36782. https://doi.org/10.1371/journal.pone.0036782

Osvath, M., & Osvath, H . (2008). Chimpanzee (Pan troglodytes) and orangutan (Pongo abelii) forethought: Self control and pre-experience in the face of future tool use. *Animal Cognition*, 11(4), 661 – 74. https://doi.org/10.1007/s10071-008-0157-0

Partee, B. H. (1973). Some structural analogies between tenses and pronouns in English. *The Journal of Philosophy* 70(18), 601–609. http://doi.org/10.2307/2025024

Prior, A. (1967), *Past, Present, and Future*, Oxford: Oxford University Press.

Reichenbach, H. (1947). *Elements of Symbolic Logic*, New York: Dover Publications, Inc.

Roberts, W. A., & Feeney, M. C. (2009). The comparative study of mental time travel. *Trends in Cognitive Sciences*, 13, 271 – 7. https://doi.org/10.1016/j.tics.2009.03.003

Russell, B. (1905). On denoting. *Mind* 14(56), 479–493. http://doi.org/10.1093/mind/XIV.4.479

Russell, B. (1911). Knowledge by acquaintance and knowledge by description. *Proceedings of the Aristotelian Society* 11(1), 108-128. https://doi.org/10.1093/aristotelian/11.1.108

Stanley, J. & Szabó, Z. G. (2000). On Quantifier Domain Restriction, *Mind and Language*, 15.2, 219 - 261. https://doi.org/10.1111/1468-0017.00130

von Stechow, A. (2009). Tenses in compositional semantics. In W. Klein & P. Li (Eds.), *The expression of time*. Berlin: Mouton de Gruyter. https://doi.org/10.1515/9783110199031.129

Suddendorf, T. (2006). Foresight and Evolution of the Human Mind. *Science, 312*(5776), 1006–1007. https://doi.org/10.1126/science.1129217

Suddendorf, T., & Corballis, M. C. (2007). The evolution of foresight: What is mental time travel and is it unique to humans? *Behavioral and Brain Sciences*, 30, 299 – 313. https://doi.org/10.1017/S0140525X07001975

Suddendorf, T., Corballis, M. C., & Collier-Baker, E. (2009). How great is great ape foresight? *Animal Cognition*, 12, 751 – 4. https://doi.org/10.1007/s10071-009-0253-9

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson, *Organization of memory.* Academic Press

Tulving, E. (1983). *Elements of episodic memory*. Clarendon Press.

Woodruff, G., & Premack, D. (1979). Intentional communication in the chimpanzee: The development of deception. *Cognition, 7*(4), 333–362. https://doi.org/10.1016/0010-0277(79)90021-0

Zhao, R. (2023). The English past tense as a definite description. *Glossa: a journal of general linguistics* 36(1). https://doi.org/10.16995/glossa.5699