Remembered Futures and Anticipated Pasts: The Recursive Grammar of Mental Time Travel

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Abstract

One feature of mental time travel is the ability to recursively embed temporal perspectives across different times: humans can remember how we anticipated the future and anticipate how we will remember the past. This recursive structure might be formalised in terms of a "grammar" that is reflective of but more general than linguistic notions of absolute and relative tense. Here I provide a foundation for this grammatical framework, emphasising a bounded (rather than unbounded) role of recursion in supporting mental time travel to a limited temporal depth and to actual and possible scenarios. Anticipated counterfactual thinking, for instance, entails three levels of mental time travel to a possible scenario ("in the future I will reflect on how my past self could have taken a different future action") and is implicated in complex human decision-making. This perspective calls for further research into the nature and origins of recursive mental time travel.

Keywords: recursion; metarepresentation; memory; prospection; counterfactual thinking; iteration

When you were a child, what did you want to do when you grew up? When you reach the end of your life, how do you think you'll look back on what you actually did? Humans can not only mentally travel to the past and future, but also remember our past anticipations and anticipate our future remembrances. We can likewise remember how we once remembered the past, anticipate how we will later anticipate the future, and even anticipate how we will remember our anticipations—and later remember those anticipated remembrances of our anticipations. If you've lost track of all these temporal levels, perhaps consider that if you've ever reflected on a past mistake and thought to yourself "I knew I would regret doing that", then you were essentially remembering (level 4) how you anticipated (level 3) that you would eventually reflect on (level 2) that mistake and wish you'd chosen a different future (level 1). At face value, such multi-layered mental time travels are recursive (Corballis, 2011; Suddendorf & Corballis, 2007), in that the cognitive processes responsible for representing a temporal perspective seem to call upon those same cognitive processes to represent another temporal perspective with hierarchical structure.

Linguists have long alluded to a recursive structure of human temporal thought (e.g., Lodge, 1910; Murray, 1795), demarcating relative tense forms such as *past perfect* (remembered past-orientation), *future perfect* (anticipated past-orientation), *future in the past* (remembered future-orientation), *future in the future* (anticipated future-orientation), and even *future perfect in the past* (remembered anticipated past-orientation). Indeed, Corballis (2007, 2011) proposed that such tense forms, which do not appear in all languages, are but one manifestation of a universal human ability to recursively embed past and future minds. Psychologists working directly on mental time travel, nonetheless, typically employ a shallower taxonomy of temporal thought, largely restricting our study to the cognitive equivalents of absolute tense: *simple past* and *simple future*. This is not to say that work on recursive mental time travel is entirely absent. There is, for instance, a healthy tradition of research on the cognitive equivalent of *conditional perfect* tense—counterfactual thinking—in which one imagines what the present would look like had a past contingency been otherwise (Beck, 2020; De Brigard & Parikh, 2019; Rafetseder & Perner, 2014). Yet, with a few cursory exceptions (e.g., Gautam et al., 2019; Hoerl & McCormack, 2016; Redshaw & Suddendorf, 2020; Schidelko, 2023), there has been remarkably little acknowledgement that this form of counterfactual thinking entails mental time travel to an alternative future—from the relative perspective of the absolute past. More generally, what seems to be lacking is an integrative framework of the recursive "grammar" of mental time travel that incorporates both absolute and relative temporal reference.

Here I lay the groundwork for such a framework, intending that it may be further developed, refined, and formalised in future work. This groundwork is itself inspired by the ideas of Suddendorf and Corballis (Corballis, 2007, 2011, 2014; Suddendorf, 2013a; Suddendorf et al., 2009; Suddendorf & Corballis, 2007), who have previously made cases for the importance of recursive processes in temporal cognition. I nonetheless extend their ideas by delimiting two different forms and roles of recursion in human mental time travel, by distinguishing several non-recursive and recursive expressions of temporal cognition, and by continuing some recent efforts (Carey et al., 2020; Gautam et al., 2019; Redshaw & Suddendorf, 2020) to amalgamate work on mental time travel with work on modal cognition (i.e., reasoning over possibilities; Leahy & Carey, 2020; Redshaw & Ganea, 2022). I also introduce a preliminary bracketed notation by which to classify recursive mental time travel, and suggest how and why the recursive depth of mental time travel may be limited in humans. A number of my arguments draw on thought experiments and conjecture rather than compelling data, providing the impetus for further conceptual and empirical inquiry.

In what sense is mental time travel recursive?

While it is evidently possible to delineate a recursive structure of mental time travel, it is less clear just how—or even if—this structure is cognitively substantiated. As has been argued for language (Christiansen & Chater, 2015;

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Heine & Kuteva, 2007), it is possible that the apparently recursive structure of mental time travel is merely an artefact of the human capacity to recognise and formulate such structure, rather than reflecting any underlying (neuro)cognitive processes that call upon themselves. It may instead be, for instance, that each apparent representational level is substantiated via a distinct cognitive process, or that all concurrently represented levels are somehow "chunked" in a non-hierarchical manner. By contrast, if one gives credence to the language of thought hypothesis—which broadly posits that thought has a syntactical structure analogous to that of language (Fodor, 1975; Quilty-Dunn et al., 2023)—then the simple fact that we can formalise a coherent recursive (i.e., syntactical) structure of mental time travel provides circumstantial evidence for the veracity of that structure (also see Mahr & Schacter, 2023). As will become clear, thinking of mental time travel as a recursive process at the very least provides a useful means for cognitive scientists to identify and study various forms of temporal thought both common and rare in humans—both on the strong version of my proposal (mental time travel is a recursive cognitive process) and the weak version of my proposal (mental time travel can be systematically modelled as a recursive process).

Although I cannot hope to resolve the fundamental question of whether mental time travel truly is recursive here, I do hope to strengthen the contention (Corballis, 2011, 2014) that it shares some very suggestive similarities with other processes traditionally conceived of as recursive. In linguistics and computer science, the term "recursion" has two related but distinct meanings (Karlsson, 2010; Parker, 2006). One sense of recursion, *tail recursion*, roughly involves taking a series of complete elements and then adding another element of the same category to either end of the series. Drawing on similar illustrations (Christiansen & Chater, 2015; Corballis, 2011), here is a linguistic example of tail recursion with six elements (i.e., six verb phrases):

> (i) *The farmer yelled at the dog that barked at the cat that chased the rat that bit the mouse that ate the cheese that sat in the field.*

The other sense of recursion, *nested recursion* (or centre-embedded recursion), roughly involves partitioning one element of a series and embedding a second element of the same category, such that the second element is called upon and completed before the first element completes. Here is a grammatically correct linguistic example of nested recursion with six elements, which is equivalent to example (i):

> (ii) *The cheese that the mouse that the rat that the cat that the dog that the farmer yelled at barked at chased bit ate sat in the field.*

Online comprehension of sentences with tail recursion, like (i), is not bounded by the total number of elements in the series, such that we can first grasp the relation between A and B, and then the relation between B and C, and so on. An equivalent sentence with nested recursion, like (ii), by contrast, can be unintelligible (Corballis, 2011).

Mental time travel appears to exhibit analogous online processing constraints as sentences with nested recursive structure. It seems implausible, for instance, that anyone would anticipate remembrance of anticipated anticipation of remembered anticipation of remembered remembrance of anticipation, whereas mere anticipated remembrance of anticipation (e.g., "I would regret doing that") is within our grasp. One possible explanation for these comparable constraints is that higher-level mental time travel entails nesting a representation of one's own mind from a given time within another representation of one's own mind from a different time (Corballis, 2014; Suddendorf & Corballis, 2007). This *representational nesting* need not be episodic in character, such that one might simultaneously represent the episodic perspectives of all the different "selves" at all temporal levels. Instead, the nested structure could be encoded propositionally (see Mahr & Schacter, 2023), with one able to mentally attend to and switch between any episodic perspective in a serial manner (see the next section for an elaboration of such propositional encoding).

Notably, previous frameworks of mental time travel have already expounded upon the role of recursive operations in the human capacity for *generative thinking*: the ability to imagine whatever, wherever, whenever (Corballis, 2011; Suddendorf, 2013a; Suddendorf et al., 2009; Suddendorf & Busby, 2003). In Suddendorf and Corballis' (2007) theatre metaphor of mental time travel, for instance, the "playwright" populates the mental stage with imagined actors, objects, and settings in a discretely infinite manner (see Chomsky, 1965), functioning to enable the unbounded construction of potential future scenarios. But this notion of recursion is more reflective of tail recursion than nested recursion, in that the elements of generative thought accumulate within a single imagined scenario playing out over time, rather than being hierarchically organised across different scenarios. Indeed, whereas the capacity for generative thinking might be considered to increase the breadth of mental time travel in an unbounded fashion, the capacity for representational nesting might be considered to increase the depth of mental time travel in a bounded fashion.

A recursive representational hierarchy

This section outlines a hierarchy of representations that illustrate the nested recursive structure of mental time travel. As will become clear, each of these representations varies on three pertinent dimensions. First, only some representations are nominally *recursive*, in that the cognitive processes involved in representing a temporal perspective seem to call on those same cognitive processes to represent another temporal perspective with hierarchical structure. Second, these representations vary in *multiplicity*, in that some refer to a series of singular perspectives and events structured across time, whereas others refer to merely possible events with represented or implied alternatives (equivalent to the conditional mood in language). Third, these representations vary in *relative temporal structure*, or the unique structure of past-oriented and future-oriented temporal relations among

the encoded perspectives and events (as exemplified by the difference between remembered anticipation and anticipated remembrance).

The section is primarily organised according to the maximum level of recursive nesting entailed in a given representational structure. I commence at level 0, emphasising that some basic forms of temporal cognition may not be recursive and yet might still have important functions. I then move on to level 1 (encompassing episodic memory and episodic foresight), which is arguably the first recursive level of mental time travel, before progressing through higher and more unambiguously recursive levels. From level 1 onwards I implement a preliminary bracketed notation to signify the relative temporal relations between the different levels of representational structure, with relatively past-oriented perspectives denoted by {past} and relatively future-oriented perspectives denoted by {future}. In this notation, the level 1 representation—i.e., the only representation that does not call upon another representation—is always denoted in the innermost brackets. A recursive representational structure with three levels might thus take the general form of {level3{level2{level1}}}, as exemplified by {past{future{past}}}. As will be clarified, however, such representational structures might also be considered to incorporate one's *present* perspective at the outermost level, taking the general form of {present{level3{level2{level1}}}} and exemplified by {present{past{future{past}}}}. This notation has the advantage of encompassing all cognitive equivalents of relative tense forms (e.g., past perfect and future perfect), alongside forms of temporal thinking that have no tense equivalent in English or any other language. Still, the notation lacks precision in some respects, and I discuss potential revisions towards the end of the article.

Level 0

Some cognitive processes seem to refer to past or future events and yet do not have recursive structure and do not even involve mental time travel. In particular, these cognitive processes lack *autonoesis*—conscious awareness of represented experiences as being located in the past or future—which Tulving (1985, 2005) classically identified as an essential component of episodic cognition. Mind-wandering, for instance, often involves representations of past or potential future events (Spronken et al., 2016), and yet much of mind-wandering occurs without awareness (Seli et al., 2016)—as when reading a boring passage of text and suddenly realising that your mind had drifted off while your eyes were still scanning the page. Such involuntary mind-wandering might have originally evolved as a precursor to full-blown mental time travel, functioning to prompt animals to act with reference to past or potential future events without having to represent these events as being located at particular times (Redshaw, 2014). Hoerl and McCormack (2019) make a similar case for a primordial *temporal updating system*, which might enable an animal to maintain a tenseless representation of its broader environment (i.e., beyond its current sensory scope) and the actions it might take there.

Other neurocognitive processes that appear to refer to past or potential future events without necessarily requiring autonoesis include hippocampal replay and pre-play sequences, which map out particular spatial routes in an animal's immediate (Kay et al., 2020; Pfeiffer & Foster, 2013) or broader environment (Karlsson & Frank, 2009; Wilson & McNaughton, 1994). Among rodents—and probably other mammals—replay and pre-play sequences correlate with actual past and future behaviour, potentially functioning to consolidate memories and aid navigational decisions (Gupta et al., 2010; Mahr & Fischer, 2023; Pfeiffer, 2020). These sequences also, however, typically play out around ten times faster than in situ navigation (Diba & Buzsáki, 2007), rather than playing out in roughly real time as human mental time travel is often conceived of (Suddendorf et al., 2022). Indeed, as Comrie et al. (2022) emphasise, such hippocampal activity "can be understood at the level of the brain and need not entail conscious awareness or mental imagery". It seems unlikely, therefore, that that this activity is essentially autonoetic in and of itself.

Intriguingly, there is some evidence that hippocampal pre-play sequences can rapidly cycle between two alternative possible future actions via the theta rhythm (Kay et al., 2020), and that "replay" sequences often encode counterfactual past actions rather than actual past actions (A. Carey et al., 2019; Gillespie et al., 2021). Such representations might function to enable animals to select between and act with reference to mutually exclusive alternatives, without necessarily understanding the mutually exclusive relation that links such alternatives (Redshaw & Ganea, 2022; Redshaw & Suddendorf, 2020) or even being consciously aware of each alternative (Comrie et al., 2022). Indeed, assuming that these representations are not accompanied by autonoesis, it would appear that even rudimentary, non-recursive temporal representations can encode multiplicity. Such level 0 representations of alternative future and counterfactual past possibilities might thus be conceived of as "pseudo" forms of the mental time travel with multiplicity that I cover below.

Level 1

The bulk of direct work on mental time travel has examined level 1 processes: *episodic memory* (Tulving, 1983) and *episodic foresight* (Suddendorf, 2010; also called *episodic future-thinking*, Atance & O'Neill, 2001). By definition, these processes entail the autonoetic awareness that one is mentally projecting oneself through time (Tulving, 1985, 2005). What is less clear, however, is whether level 1 mental time travel qualifies as recursive. At face value it is non-recursive (Suddendorf & Corballis, 2007), in that the cognitive processes responsible for generating a mental scenario do not seem to be called upon to generate another mental scenario with hierarchical structure. If, however, autonoesis depends on the metarepresentational understanding that one's *present* mind can hierarchically represent one's past or future mind (Corballis, 2011, 2014)—thus endowing mental time travel

with its temporal quality (Redshaw, 2014)—then it follows that episodic memory and foresight are indeed recursive with temporal structures of {present{past}} and {present{future}}. Although this distinction might seem trivial, the recursiveness or non-recursiveness of autonoesis could prove one key to progressing the controversy surrounding whether non-human animals are capable of mental time travel (Cheke & Clayton, 2010; Corballis, 2013; Hoerl & McCormack, 2019; Martin-Ordas, 2020; Osvath & Martin-Ordas, 2014; Suddendorf, 2013b; Suddendorf & Corballis, 2007). If, for instance, it was conclusively demonstrated that autonoesis entails recursive cognition, then one might be less inclined to attribute level 1 mental time travel capacities to animals (who show no compelling evidence of recursive communication) than if it was shown that autonoesis does not entail recursive cognition. I do not intend to resolve this question one way or the other here, but for the sake of consistency I will continue to incorporate the present mind when denoting relative temporal structure.

Level 1 mental time travel can vary in multiplicity, in that we are not constrained to imagining only one version of an event located at a given time. Multiplicity is often evident in episodic foresight, for instance, when you imagine and compare mutually exclusive versions of a single future event—with a plural temporal structure of {present{futures}}. This process can be as simple as imagining and preparing for two possible paths that an object might take (Beck et al., 2006; Redshaw & Suddendorf, 2016), or as complex as evaluating several possible career choices you might make. Redshaw and Suddendorf (2020) have argued that an explicit understanding of mutually exclusive futures entails a capacity to represent *temporal junctures*, or points in time where subjectively possible versions of reality diverge from one another like a fork in the road. Nonetheless, it is also common to compare different futures without representing temporal junctures, as when you might compare a utopian future to a dystopian future without necessarily imagining the contingencies that could lead to one or the other. But because such cases lack a represented temporal relation linking the alternatives (i.e., a temporal juncture), it may be more accurate to conceive of them as entailing multiple distinct representations with singular structure—{present{futureA}} and {present{futureB}}—rather than an integrated representation in the form of {present{futures}}.

It is likewise possible to compare level 1 representations of the past without representing temporal junctures, with these representations having distinct singular structures of {present{pastA}} and {present{pastB}}. You might make such a comparison, for instance, when asked to rank two job candidates based on their interview performances. However, because represented temporal junctures inherently face forward with the arrow of time (Redshaw & Suddendorf, 2020), it is not clear that it makes sense to delineate level 1 mental time travel structures with integrated past multiplicity in the form of {present{pasts}}. Rather, as will be clarified, representing alternative pasts within the same hierarchical structure might necessitate level 2 mental time travel.

Level 2

At the second level and above, the structure of mental time travel is more unambiguously recursive (Suddendorf & Corballis, 2007), even among instances without multiplicity. Some such instances have a {present{past{past}}} structure, as when recalling what someone else told you about a past event (i.e., hearsay), whereas others have a {present{future{future}}} structure, as when you propose a meeting at which you will plan an upcoming event. Conversely, you might recall what someone else told you about their plan, structured {present{past{future}}}, or propose a meeting to discuss a recent incident, structured {present{future{past}}}. Level 2 mental time travel can also take forms with both recursiveness and multiplicity, like {present{future{futures}}}, {present{futures{future}}}, or even {present{futures{futures}}}. The final form, for instance, would encompass a situation where a group must decide between two possible meeting venues (level 2), at which they will discuss which of two possible plans they will enact (level 1). Thus, recursive mental time travel with multiple future-oriented perspectives can incorporate temporal junctures at both higher and lower levels.

Much of the relevant work on level 2 mental time travel has examined *counterfactual thinking*. Although this term has alternative meanings (Beck, 2016; Weisberg & Gopnik, 2013; Weisberg & Gopnik, 2016), one research tradition holds that counterfactual thinking involves mentally undoing an actual past event and imagining what the present would look like had an antecedent of that event unfolded otherwise (McCormack et al., 2018; Rafetseder et al., 2010; Rafetseder & Perner, 2014). After missing an early morning meeting, for instance, you might think to yourself "if only I had set my alarm last night…" or "if only my bus had arrived on time…". Implicated in this process is the recognition that, in the absolute past, there were alternative ways the relative future could have unfolded (Gautam et al., 2019; Hoerl & McCormack, 2016) at a temporal juncture (Redshaw & Suddendorf, 2020). This form of counterfactual thinking thus has a temporal structure featuring both recursiveness and multiplicity, {present{past{futures}}}.

Counterfactual thinking appears to have many important functions in human cognition and behaviour (Redshaw & Ganea, 2022). Causal judgements about past events, for instance, have been proposed to rely on counterfactual simulation, with experiments showing that adults tend to judge that object X caused event Y if and only if event Y would not have eventuated in the case that object X was absent (Gerstenberg, 2022; Gerstenberg et al., 2021). Counterfactual thinking also supports moral judgements, such that people (including children aged 6 years and older; Gautam et al., 2023; Wong et al., 2023) tend to make stronger judgements about a character's "good" or "bad" action if that character had a counterfactual choice available to them at the time. People similarly tend to make stronger judgements about their own past actions if there were counterfactual alternatives available at the time (Gautam et al., 2022; Jones et al., 2024; Weisberg & Beck, 2012). The counterfactual

emotions of regret (McCormack et al., 2020) and relief (Graham et al., 2022), for instance, arise when you consider that you could have taken a better or worse past action, respectively, than your actual past action. Accordingly, the *functional theory of counterfactual thinking* (Epstude & Roese, 2008) suggests that people tend to focus on counterfactuals that were within their own control (e.g., "I wish I had brought my umbrella") rather than counterfactuals that were out of their control (e.g., "I wish it hadn't started raining"), given that only controllable factors can be altered in similar future situations (also see Schacter et al., 2015). That is, counterfactual thinking with the level 2 form of {present{past{futures}}} may often function to aid mental time travel with the level 1 form of {present{futures}}.

Level 3

From level 3 onwards, the range of conceivable temporal structures considerably expands. Some of these structures may be rarely expressed, including the one-way journeys of {present{past{past{past}}}} and {present{future{future {future}}}}. It is nonetheless plausible, for instance, that you would set a reminder in your calendar for tomorrow morning (level 3), because you plan to contact your colleagues to propose a meeting (level 2) at which you will plan an upcoming event (level 1).

Perhaps the most common form of level 3 mental time travel is *anticipated counterfactual thinking*, in which one foresees looking back on a relative past decision and imagining what else one could have done (Gautam et al., 2019; Hoerl & McCormack, 2016) at the relevant temporal juncture (Redshaw & Suddendorf, 2020). Anticipated counterfactual thinking can take one of two temporal structures. The first structure, {present{future{past {futures}}}}, entails a situation in which you have already taken a particular course of action, yet you nonetheless recognise that in the future (level 3) you will continue to reflect on that past action (level 2) and consider what would have happened following an alternative course of action (level 1). Such thinking might be common, for instance, after making an especially consequential life choice like accepting a job offer or immigrating to a new country—i.e., "I will always wonder what my life would have been like if I did not...". The second structure of anticipated counterfactual thinking, {present{futures{past{futures}}}}, entails a situation in which you have yet to make up your mind about a future course of action, and for at least one possible future action (level 3) you consider how you would eventually reflect on (level 2) that action and its alternatives (level 1).

Anticipated counterfactual thinking with the first structure may function in a similar manner to level 2 counterfactual thinking, in that it may prompt us to make better decisions when confronted with similar future choices with the level 1 form of {present{futures}}. Anticipated counterfactual thinking with the second structure, however, appears much more straightforwardly functional, in that it can prompt us to make a better decision before any such decision has been made. One common domain in which such thinking may prompt better decisions is intertemporal choice, in which an agent is confronted with a decision between a smaller, sooner reward or a larger, later reward (Berns et al., 2007). For instance, by considering that you might eventually (level 3) look back with regret (level 2) at choosing the tempting sooner reward (level 1), you may be more likely to take the alternative level 1 action of choosing the later reward (see Bulley & Schacter, 2020). Anticipated regret is likewise a strong predictor of health-related choices (Brewer et al., 2016), including in the domains of exercise (Abraham & Sheeran, 2004), nutrition (van Koningsbruggen et al., 2016), and vaccine uptake (Lorimer et al., 2024). Indeed, whereas the functional theory of counterfactual thinking (Epstude & Roese, 2008) itself has only mixed empirical support (Mercier et al., 2017), the functional value of anticipated counterfactual thinking in the form of {present{futures{past{futures}}}} is almost self-evident.

Higher levels

Recursive mental time travel beyond level 3 is sometimes feasible (Redshaw & Suddendorf, 2020). You can likely, for instance, recall a past moment of anticipated counterfactual thinking, with such recollection perhaps taking the level 4 form of {present{past{futures{past{futures}}}}}. If you squint hard enough, you might even be able to imagine how you would recall that moment of anticipated counterfactual thinking tomorrow, with a level 5 form of {present{future{past{futures{past{futures}}}}}}. Alternatively, you might remember the beginning of this article, where I asked you to reflect on a level 4 moment of thinking "I knew I would regret doing that"—such that your current remembrance (level 6) of that prompted reflection (level 5) now takes the form of {present{past{past{past{futures{past {futures}}}}}}}. Alas, I suspect it might be more tempting to chunk the lower five levels together and simply remember (level 2) that you read such a passage that asked you to reflect on a past moment (level 1).

Evidently, such high levels of mental time travel can be cognitively taxing and impractical. As outlined earlier, the proximate explanation for this difficulty might involve a limit on the number of nested relations humans can concurrently entertain. Ultimately, however, there might be little selective pressure to further expand this limit, given that higher limits might have rapidly diminishing returns. Indeed, whereas a soft limit of 3 levels of mental time travel is plainly useful from an evolutionary standpoint—in that it provides the means to pre-experience delayed emotional consequences of level 1 decisions (via anticipated regret and relief)—there is no such obvious gain to be drawn from higher levels. It is even feasible that higher levels of mental time travel could lead to maladaptive decision hesitancy, in that it might be difficult to resolve the intrapersonal conflict that would arise between more and more versions of the self represented across time. Accordingly, consistent with the *Goldilocks principle* (e.g., Hill et al., 2016; Kidd et al., 2014), humans might have evolved a soft limit on recursive mental time travel that is "just right" to support adaptive decision-making.

Links with other recursive capacities

Besides mental time travel, another obvious candidate for an evolutionary driver of nested recursive thinking is theory of mind, which has an analogous hierarchical structure of minds within minds (Corballis, 2011; Redshaw & Suddendorf, 2020; Schidelko, 2023). Arguably, level 0 expressions of theory of mind include implicit belief tracking, whereby infants (Onishi & Baillargeon, 2005) and non-human great apes (Krupenye et al., 2016) appear to predict the belief-driven actions of another agent without necessarily reasoning about or even being conscious of the very beliefs driving those actions (Perner & Ruffman, 2005; Rakoczy, 2022). Level 1 theory of mind, by contrast—if taken to be recursive—would encompass any situation in which one possesses the metarepresentational understanding that one's own mind is representing another mind in the form of {me{other}}, regardless of whether the represented content of that other mind is congruent or incongruent with the content of one's own mind. Again, higher levels of theory of mind are more unambiguously recursive, as per second-order belief understanding (Perner & Wimmer, 1985) and third-order belief understanding (Osterhaus & Koerber, 2021). Level 3 theory of mind, for instance, can take the form of {me{other{me{other}}}}, as when you recognise that another person thinks (level 3) that you have a false belief (level 2) about what that person knows (level 1). It can also take forms such as {me{other3{other2{other1}}}}, as when you recognise what person 3 thinks (level 3) about what person 2 thinks (level 2) about what person 1 thinks (level 1).

One property of recursive mental time travel and theory of mind is that it is feasible, and perhaps common, to engage these processes concurrently. Level 3 mental time travel, for instance, can be readily combined with level 3 theory of mind, as when you might anticipate (level 3) that you would immediately regret (level 2) correcting a friend's minor misconception (level 1), for fear that she might form the false belief (level 3) that you think (level 2) that she knows little about the subject (level 1). Although the total number of recursive relations entailed in this example is 6 (if one accepts level 1 thinking as recursive), the maximum recursive depth is only 3. The apparent ease of processing such combined instances—as compared to processing standalone mental time travel and theory of mind instances with a recursive depth of 6—suggests that the limits of recursive thinking may lie in maximum recursive depth rather than in the total number of recursive relations entertained per se.

Conclusions and future directions

Here I have outlined a preliminary framework of the recursive grammar of mental time travel. This framework distinguishes tail recursive and nested recursive processes, delineates numerous non-recursive and recursive forms of temporal thought, and introduces a notation by which to identify and categorise recursive forms. There are, however, many open questions, including about the fundamental validity of formulating mental time travel in recursive terms.

Despite these open questions, the framework makes clear predictions about the developmental trajectory and phylogenetic distribution of temporal cognition. In particular, it suggests that children and animals should never be capable of nominally higher-level forms of mental time travel without also being capable of nominally lower-level forms (at least when holding multiplicity constant). One challenge for this area, however, is to design experiments that can distinguish between (i) behaviour that is genuinely underpinned by mental time travel processes with recursive structure, and (ii) behaviour that is instead underpinned by non-recursive, pseudo mental time travel processes such as those outlined in the Level 0 section. This will not be an easy challenge, as foreshadowed by related ongoing debates about whether young children (Alderete & Xu, 2023; Leahy, 2024; Leahy & Carey, 2020; Redshaw & Suddendorf, 2016; Turan-Küçük & Kibbe, 2024) and non-human primates (Engelmann et al., 2023; Lambert & Osvath, 2018; Redshaw & Suddendorf, 2016, 2020) can represent mutually exclusive futures in the integrated form of {present{futures}}. Nonetheless, if the addition of nested recursive structure to temporal cognition is indeed evolutionarily meaningful, then it must be tractable to natural selection and thus also to experimental inquiry.

On a more procedural note, the bracketed notation I have introduced here is illustrative but underdeveloped, in that it calls attention to the key aspects of the representational hierarchy under consideration while also lacking precision. The notation {present{past{future}}}, for instance, does not specify whether the relative future (from the perspective of the past) is situated in the absolute past, present, or future. A more precise notation might incorporate positive and negative subscripts to denote absolute time (with present time set at 0), such that $\{present_0\{past_{-1}\{future_1\}\}\}$ indicates that the relative future is in the absolute future, $\{present_0\{past_{-1}\{future_0\}\}\}$ indicates that the relative future is in the absolute present, and $\{present_0\{past_{-2}\{future_{-1}\}\}\}$ indicates that the relative future is in the absolute past. The illustrative notation also does not distinguish between the total number of possible futures under consideration for a future-oriented perspective with multiplicity. This aspect might be denoted with superscripts, such that $\{present_0\{past_{-1}\{futures_0\}^2\}\}$ would indicate counterfactual thinking with two represented possibilities, whereas $\{present_0\{past_{-1}\{futures_0\}^3\}\}$ would indicate counterfactual thinking with three represented possibilities (e.g., "it could have been *better* than it *is*, but it also could have been *worse*").

The concept of recursion appears to hold much promise for furthering our understanding of complex human cognition, well beyond its traditional applications in linguistics. But whereas other influential frameworks have proposed a broader role of recursion in producing discrete infinity, the current framework emphasises that more finite expressions of recursion might have been similarly important in making humans who we are. We might not be able to endlessly embed minds within minds across different times, but the limited temporal depths that we can traverse might have been just right for opening new frontiers of thought and behaviour.

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