

Research



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Memory, mental time travel and The Moustachio Quartet

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Mental time travel allows us to revisit our memories and imagine future scenarios, and this is why memories are not only about the past, but they are also prospective. These episodic memories are not a fixed store of what happened, however, they are reassessed each time they are revisited and depend on the sequence in which events unfold. In this paper, we shall explore the complex relationships between memory and human experience, including through a series of novels 'The Moustachio Quartet' that can be read in any order. To do so, we shall integrate evidences from science and the arts to explore the subjective nature of memory and mental time travel, and argue that it has evolved primarily for prospection as opposed to retrospection. Furthermore, we shall question the notion that mental time travel is a uniquely human construct, and argue that some of the best evidence for the evolution of mental time travel comes from our distantly related cousins, the corvids, that cache food for the future and rely on long-lasting and highly accurate memories of what, where and when they stored their stashes of food.

1. Introduction

Our ways of seeing [1] are based on memory and the anticipation of what comes next. There are those that argue this is all there is. Memory is a foreign land that only exists in the present, the space where all life exists. Would the world's archives make sense, if there were no one there to access the meanings of all that went before? It could be argued that time, and the way in which we use it, is a uniquely human concept, and not one that is replicated in the wider universe. The concept of mental time travel, that ability to travel backwards and forwards in the mind's eye in order to contextualize the present, is well known. However, we are probably out of step with the universe by assuming that time can move backwards and forwards, at least physical time. If we look for evidence of time in the wider universe, all we have been able to detect are a series of unfolding events that move remorselessly in one direction. This is the process of entropy, which goes so far as to suggest that there is no way to unbreak an egg. The thesis that follows comes out of such observations.

The anomalies that occur in our thinking are fascinating, and outside of science can be observed in the art and writing of our cultures across millennia, an analysis of which suggests that memories are curious things and are central to our everyday lives and make us who we are, and cause us to question the very nature of reality. We shall argue that memories are made for the future not the past, and reconstructed each time they are revisited. Facts about the past are preserved although the complexion of how they are remembered changes; in consequence of which none of these things are an accurate record of what happened, despite our own underlying prejudice. That is because what we remember becomes what happened: the revisiting of memories results in the re-contextualizing of thoughts, and the updating of perceived knowledge.

This ability to project the self in time allows us to imagine events that have never happened and to travel to places to which we have never been, other than in the mind's eye. We swim in a subjective sea of time, which changes from moment to moment, surrounded by an ever-present awareness that what once was the future will soon become the past and that the real future will

never be quite the one we imagined. Without memory, thought would have no anchor. Memory allows us to use the past to create the future, it is the trigger to inspire new ideas, and generates the flexibility in our imagination that allows us to do so, all be it embedded within the scaffold of what we already know. We contextualize the present and the future: in such ways, we embody mental time travel as a primary resource for making sense of our subjective experience. Our personal memories of the past are intimately entwined with our thoughts about the future. We rely on our episodic cognition, our mental time travel system, to reminisce, this being one reason why our memories need to travel forwards as well as backwards in time.¹ In this paper, we shall explore notions of memory and mental time travel. In so doing, we examine convergent evidence, adopting a comparative analysis that interweaves science with the arts, investigating both human and non-human animals.

2. What are the core features of mental time travel?

It was Tulving [2] who coined the term episodic memory to clarify that our ability to remember the past is a psychologically distinct process from other forms of memory such as body memory (procedural memory) and knowing facts about the world (semantic memory). Tulving identified two key phenomenological features of memory and mental time travel, namely autooiesis and chronesthesia [3,4]. Autooiesis refers to a special kind of self-consciousness that allows us to reflect upon our memories, knowing that we are the authors and owners of those thoughts. So what we have done in the past becomes a part of our self and the ability to reflect upon this influences our behaviours in the present (see also [5]). 'It's no use going back to yesterday, because I was a different person then' said Alice in Lewis Carroll's [6] clever tale *Alice's adventures in wonderland*. Memory is the door to identity: it shapes who we are [7] although it does not destroy it (see [8] for example). Chronesthesia refers to another kind of consciousness that lies at the heart of memory, namely our awareness of the passage of time, of being able to travel backwards and forwards in the mind's eye to revisit the past in order to anticipate how we might position ourselves in the future.

These phenomenological features of episodic memory have been impossible to access in non-human animals to date, owing to the lack of agreed behavioural markers of consciousness in non-linguistic creatures. There are accompanying behavioural features of memory and mental time travel that Tulving originally referred to as the spatio-temporal relations between events [9]. In essence, this is the ability to form integrated episodic-like memories of what happened where and when [10], which allows the subject to discriminate between similar episodes that occurred at different times and/or locations [11]. This information can be deployed flexibly not only for memories of the past, but also to imagine and plan for future events [12,13]. It is these behavioural criteria of mental time travel that can be assessed in non-human animals, a point to which we shall return later.

Tulving [9] was also the first to make the distinction between remembering and knowing. Knowing requires the use of semantic cognition, the ability to acquire and store facts about the world, but such knowledge of the past and future does not necessarily require an awareness of either

the projection of the self or time, and largely consists of a series of selfless, timeless labels (the obvious exception being the semantic knowledge of one's birth date, which is not accompanied by any episodic remembrance of the actual birth). By contrast, remembering requires a separate, all be it embedded system, namely that of episodic cognition, the ability to project the self in space and time to imagine the future and recall the past. As William James so eloquently remarked [14, p. 6509], 'Memory requires more than the mere dating of a fact in the past, it must be dated in my past. In other words I must think that I directly experienced its occurrence'. This is not to say that the semantic system plays no role however. Indeed, semantic scaffolding hypothesis argues that semantic memory provides a crucial scaffold in which to embed the subjective experiences, a framework with which to evaluate and contextualize the episodic contribution to past and future [15,16] (see also [17] for a current review).

As we alluded to in the Introduction, remembering is subjective and the interpretation of one's thoughts is open to conjecture and review whenever it becomes necessary to recall them. The process is beautifully described in the following: 'You don't remember what happened. What you remember becomes what happened' as Green [18] expressed in his amusing novel, *An abundance of Katherines*. As in life, stories rely heavily on the sequence in which events unfold and this colours the way in which we interpret our perceptions and our memories. The reconstructive nature of memory has its scientific origins in the work of Bartlett [19]. In his book *Remembering*, he describes a study in which participants read and then retell a North American Indian folktale *The war of the ghosts* involving a battle between ghostly warriors. The participants distorted the story to fit in with their pre-existing knowledge structures, omitting the sections that seemed irrelevant, and changed the emphasis and structure of the story to match their own experience of how the world works.

It is now well established that our episodic memories of past events can change each time we revisit them, depending on our mood and point of view. This causes us to frequently question the authenticity of memory, pondering the validity and meaning of experience: What was real, what was imagined; what, if any of it at all, will be real tomorrow? Our thoughts and perceptions of the past and future are transformed through time. Sometimes, the alterations that ensue create a false memory that never actually happened. The seminal studies of Elizabeth Loftus have revealed how easily memory recall can be manipulated through language, overriding the perceptual feedback of the event itself [20–22]. For example, when participants were asked to view videos of a car accident with collisions at 20, 30 and 40 miles an hour, respectively, and then asked to judge how fast the cars were going when the accident occurred, their responses were primarily influenced not by the perceived speed at which the cars were actually going, but by the choice of words, such as 'smashed' as opposed to 'bumped', that were used to phrase the question. When asked additional details about the event such as whether or not they had seen any broken glass at the scene, participants were much more likely to report the presence of broken glass if the word 'smashed' had been used to pose the question [20]. Our memories are so malleable that they are not only reconstructed but in some cases misconstrued [23]. A case in point is the way in which magic effects work in the mind successfully disorientating and obscuring our perception and ability to remember what happened.

Our awareness of these notions is explored in the following extract from *The Moustachio Quartet* [24, p. 48]:

Xavier had launched himself, before midnight, into the darkened city, to follow his idiosyncratic and nocturnal inclinations, to take note of the confusing world he found himself in and to wonder. In the gloom, he had followed the lines of the streets with his thoughts and had eventually found himself at the tango by the river. The dancing was glorious and he had lost himself to moments that opened up for him. The release, as ever, had been joyous; he felt he was outside of time. The spirit of the experience flashes before him; he observes it, remotely quantifying the sensations, checking and wondering if his observations still matched his earlier recollection. Even in this short time, Xavier recognised that his sense of recall, his remembrance and his emotional responses had become altered in some way beyond his control. What had been missed or forgotten? What had altered?

This begs the question why episodic memories and perceptions are so labile and not simply a fixed repository of the past. The answer lies in the fact that our memories are as much about what will happen next, as about what has already occurred, and indeed, it is thought that the episodic memory system evolved for thinking about the future rather than about the past, the so-called constructive episodic simulation hypothesis developed by Schacter *et al.* [25–27]. This hypothesis posits that a crucial function of the brain is to use information gleaned from past experience to simulate a series of future scenarios and in so doing allow us not only to juxtapose a number of alternatives, but crucially to predict and plan for those possible eventualities.

This flexibility in our ability to simulate multiple points of view is great for creativity, allowing us to move our thoughts seamlessly between the past, the present and the future, and to reflect upon our thoughts and those of others, enabling us to juggle multiple perspectives involving other selves and other times—all simultaneously in the mind's eye. As we have argued previously [28], we have an internal compass that we use to orient ourselves in space and time, to project ourselves into times past and future and even into other people's lives, capturing a landscape that contains past, present and future, all of which can be accessed simultaneously. This *creative navigator's compass* comes at a cost in terms of accuracy: our attention, our perception and our memories are selective and subjective: the brain anticipates what it expects to see and makes associations accordingly. Sometimes, it can deceive itself.

A source of such deception is the obsession of the self in the current moment: we have a tendency to think that the future will be more like the present than it actually will be. Gilbert [29] describes this temporal myopia, or short sightedness, when it comes to envisioning futures, in his wonderfully entertaining book *Stumbling on happiness*: for example, he convincingly demonstrates that people's choices of what they think they will want to eat tomorrow will be heavily influenced by their current motivational state, irrespective of whether or not those states will be experienced tomorrow (see also [30]). For most of us, this is a familiar experience: it is seldom a good idea to go supermarket shopping when hungry: that is when we make ill-informed dietary choices because of our inability to dissociate current needs from possible future ones.

Such temporal myopia constrains our memories of what happened. It could be argued we fail to remember events, because we are too busy reconstructing memories to fit into our existing schema of how the world works, and in so

doing override what was actually perceived. Visual illusions and magic effects capitalize on these aspects of perception too, as does art, literature, music and dance [31]. The errors that illusions and other visual effects induce in our perceptions are systematic, revealing fundamental features of our perception. As Gilbert [29, p. 46] so eloquently states 'they are not silly mistakes but clever mistakes, ones that allow those of us who understand them to glimpse the elegant design and inner workings of the mind'. The mistakes we make when we try to imagine our personal futures and reflect upon our treasured memories are also systematic and they too have a pattern that tells us about the powers and limitations of using our creative navigator's compass to explore the world. We use our eyes to look into space, and our creative compass to circumnavigate space and time: just as our eyes sometimes lead us into seeing things as they are not, our episodic cognition can lead us to remember things falsely and foresee things as they will not be [7]. 'Boundary extension' is a classic case in point. This is the phenomenon whereby people consistently perceive and imagine a greater expanse of a scene than the one they were actually shown [32]. In essence, it is an error of commission in which people think they remember seeing a surrounding region of a scene that was not visible in the original view. Interestingly, it does not occur in response to all pictures, only those that convey scene structure, and furthermore, it does not occur for all boundaries within a scene, but only those boundaries that form the exterior to the view [33,34].

This is a phenomenon long known to painters and photographers who work within a picture plane that has a defined edge and limit. The art of composition and knowing where to finish an image is crucial to the communication of an idea. In order to make sense of an image the viewer most frequently will infer what went on moments before and will conjecture what is coming next. In addition, they infer what is beyond the boundary. In so doing, they invent more of the world and the story of that world than they were originally shown. Indeed, in a similar vein, the theatrical proscenium arch allows the audience to suspend disbelief in the imaginative or artificial worlds that they experience. In this instance, the arch although it describes the edge of the stage does not describe the edge of our imagination.

Interestingly, not all minds are subject to boundary extension. Amnesiacs are not only impaired in their ability to remember the past, but in addition cannot imagine or reconstruct complex spatial scenes [35,36] and intriguingly they do not show the boundary extension phenomenon [37], presumably because they do not have access to what we have referred to as the creative navigator's compass.

3. Convergent evidence 1

In the absence of the ability to engage in mental time travel, the mind is left stranded: in a dark place. Without the ability to engage in mental time travel, the mind is equally left stranded, but in an unknown place. The hippocampus has a critical role in the difference between the two states of mind for this in an area of the brain that plays a key role in memory and mental time travel.

Henry Molaison is undoubtedly the most famous case study highlighting hippocampal amnesia, but like many amnesiacs damage was not limited to only one region of the brain [38]. Another less well-known case is that of the British

musicologist, conductor, tenor and keyboardist, Clive Wear, known as ‘the man with the seven-second memory’,² who developed herpes simplex encephalitis causing irrevocable memory loss. Perhaps the clearest evidence, however, comes from the seminal studies of patients such as Cochrane [8,39] and DB [40], who suffered specific impairments in episodic cognition, both in terms of remembering the past and imagining the future. KC and DB know facts about the past and can conjecture information about the future, but they cannot directly experience it: when asked to do so they report that their minds go blank and that they feel the same kind of blankness when asked to remember the past or imagine the future. The striking thing here is that neither can conjure a single event into their conscious awareness. They have no subjective experiences about themselves. It is as though they were not present when the events they are asked to describe actually happened but were merely told the facts afterwards.

In analysis of amnesiacs, we see the debilitating effects of life and consciousness in the absence of mental time travel. Primarily, this results in the inability to contextualize the present. Examples abound: How can I know how I am feeling today without conscious access to a memory of how I was feeling yesterday, last week, last year? How do I know if I feel full immediately after a meal? Despite the role of autonoesis and the claim that memory is the door to identity, memory loss alone, by report, does not leave the individual without personality or individual character traits [41]. This leaves one to conjecture whether aspects of identity are carried in the way we use language and accessed by other non-episodic forms of memory.

Understanding aspects of what is lost in the absence of mental time travel makes any analysis of the fully functioning mind seem particularly incredible. The ability to marshal complex thought from a variety of viewpoints in analysis and formulate flexible strategies for thinking that provide a narrative for the future may be our greatest skill. Despite technologies that allow us to glimpse such gifts in action (e.g. functional magnetic resonance imaging), it may be the case that the fully functioning mind is still best observed in the artefacts we produce. The following extract taken from *The Moustachio Quartet* [42, p. 23], although literature no doubt, illustrates the manner in which mental time travel can be used to place the individual in time and place, in our need to understand the miasma of being and the universe writ large.

It is mid-afternoon on another imagined day. Caruso Maelstrom stands on the steel deck, his familiar, boyish gaze passing over the paint splattered, chipped railing of the P&O passenger ferry; the far distant islands appearing as miniature outcrops of blue amidst the vast, cold, glistening, shimmering sea; passing waves might roll and undulate, airborne surf pound hard against the ships prow, delivering the smell of salt water and sea into this beautiful man’s flaring, open nostrils. He senses, from what he sees, that the ocean’s surface is only marginally warmer than what lies beneath, in some other realm beyond. As he looks, sunshine and the crystal daylight radiate out across the oceanic vista, throwing the various hard territories and islands into degrees of relief, the prevailing detail determined by his proximity to their majesty and magnitude. The nearest island, green-topped and brown-faced with igneous rock weathered over millennia is known to be the nesting place for seabirds. Guillemots are there flying still—slicing through three dimensions—gliding over the formidable and available rocky landmass. Listen, the sound of their remote cries and calls can be heard even now, passing silently through the air and travelling on discreet, secret, transient breezes, the noise only briefly, temporarily deadened

by miscellaneous activity that has, in truth, happened since—within the annals of human memory. All this occurred within space and time and has become no more than a remote symphony. That clouds, light and beauty exist within his consciousness in this re-imagined moment is a reality recognised to be too brief, ephemeral and so easily lost—all this can only be remembered as belonging to a once known and impenetrably mislaid place, if it is remembered at all? Prompted by such airy thoughts the man imagines and inwardly glimpses a breath-taking void stretching out before him into an unknown and impossible distance.

The flexibility of the written narrative makes it difficult for the reader to know whether the description is happening in the present or the past or the future. Indeed, the narrator is deliberately engaged in the act of disorientating themselves in order to find a way forward in their description of impossible questions, the answer to which at the end of the short sequence remain unresolved. Nevertheless, the process of looking for clues and searching for answers without fully understanding the task in hand is intrinsic to the creative process. In the absence of knowing what to do, finding a way forward is paramount.

4. Convergent evidence 2

So far our focus has been on human mental time travel, but are we unique in the animal kingdom in having the ability to remember the past and plan for the future? There has been considerable debate as to whether mental time travel is uniquely human [43], or whether we share this cognitive ability with other animals [12,44,45]. The issue is not about whether animals can store, process and retrieve information about the past, but rather whether they use episodic cognition, the mental time travel system, to do so [2]. As we stated earlier, questions concerning autonoesis and chronesthesia in animals are at least currently outside the bounds of empirical enquiry, and it is open to conjecture whether animals experience boundary extension, such tests are yet to be conducted. What we do know, however, is that some animals can remember the what, where and when of past events and act prospectively (for recent reviews, see [13,46]) and that like humans, hippocampal activity plays a key role (for recent reviews, see [47,48]).

Some of the best evidence comes from studies of corvids, members of the crow family, whose cognitive abilities have earned them the title ‘feathered apes’ [49,50]. These birds hide food for the future and have excellent memories of specific past caching episodes: of what they hid, where and how long ago [10,51], as well as keeping track of who was watching when they cached in a particular place [52]. They can also update and generalize across situations, thereby demonstrating that these episodic-like memories can be flexibly deployed [53], and use this information to learn where and when not to cache in the future [54]. Furthermore, they can also plan for the future, knowing where to hide food for tomorrow’s breakfast [55], and when to protect their caches from potential thieves [52,56]. The jays can ignore their current needs at the time of caching in order to choose to cache those items they have learned they will want in the future when they come to recover and eat their caches [57,58]. Given the ill-informed dietary choices humans often make, as alluded to earlier, such ability seems no small feat. Perhaps the reason the jays are able to dissociate current and future needs is precisely because they are not relying on episodic cognition, that subjective experience

of thinking, which all too easily constrains our perception and our memories [59].

A number of other laboratories have subsequently investigated whether or not other animals have episodic-like cognition using paradigms analogous to those employed with the jays. There is now good evidence that a diverse range of animals can remember the what-where-and-when of past events, from cuttlefish to great apes, and that some primates are also capable of prospective cognition (see [13] for a recent review). It remains to be seen, however, whether such behavioural criteria are sufficient to ascribe episodic cognition to these animals, but converging evidence from the cognitive development literature suggests that episodic-like memory (remembering what happened where and when) and the ability to plan for the future emerge at around the same time in young children as other tests of mental time travel [46].

Additional evidence comes from neurophysiological recordings of hippocampal activity. In humans, it is well known that the hippocampus is activated when subjects consciously engage in remembering the past and imagining the future, and analogous explorations of 'replay recordings' of hippocampal activity in rodent models suggest that rats may also engage in such mental time travel (see [47] for a recent review).

5. Convergent evidence 3

The empirical testing so familiar to scientists is not the process that artists use in their form of enquiry. That is not to say that they are oblivious to the scientific method, but theirs is a process informed by an analysis of experiential concerns and self-enquiry, almost as if to say the recognition of self in its conscious state is the experiment that artists undertake. One's personal response to stimulus becomes the focus for further artistic enquiry. Often this is exemplified or embraced by the acceptance of the artist's artefacts within society and culture. The level at which such conjecture can be accepted as true is part of that enquiry. In its broadest sense activity that takes place across millennia has at least stood the test of time and resonates in some way that must be significant. In this sense, the construction of *The Moustachio Quartet* [24,42,60,61] is interesting, especially in terms of its collaborative nature as an arts-science project exploring memory and mental time travel. Each of the books features one of four characters who move over, through and across the mythical city of Warcapest. In so doing, they come across the characters from other books by accident or design.

Such structure and the ensuing matrix of unfolding ideas and events allows for conjecture about how memory and mental time travel works. This is especially significant for the reader, because the books can be read in any order. The inquisitive reader is able to understand the unfolding scenario in the order they read the books, but in addition find themselves doing the mental conjuring that allows for conjecture as to how understanding might be altered had the sequence been read differently, for this lies at the heart of the reconstructive nature of memory. Furthermore, there are choices to be made about what has been discovered and thereafter what should be remembered. The author has taken account of the reader's prior knowledge, knowing that their current state of mind will cause them to automatically make assumptions about the scenario and other associations that may exist outside of

the novels. It is implicit that the reader will reinterpret the scenario to suit their purposes and in so doing build the story in a form they understand. A good author recognizes that the story will be remembered not as they wish it to be but as the reader wishes it to be—the reader seldom remembers what happened but what they remember becomes what happened. In this respect, Warcapest, the city in which the action takes place, is a metaphor for culture and the endemic baggage it carries with it, the social history of a species as it were, replete with souvenirs and mementos and signposts that preserve and promote the collective unconscious.

In short, the narrative causes questions to be raised that lie at the heart of how memory and mental time travel works. The artifice is so shallow as to entice the reader to ask whether the main characters are similar, if not the same as one another. Indeed, how could they be different given that the author has constructed them. All these issues operating in tandem offer the opportunity to question identity and perspective taking.

6. Integrating approaches

The process of collaboration provides insight that can be found in no other way, and indeed, this is a major strength of the comparative approach, of an analysis of the converging evidences concerning memory and mental time travel. This approach allows us to recognize the patterns we use to decipher the world [1]. Integrating science and the arts allows us to focus on the common denominator of our expertise, the human mind and a comparison with animals offers a perspective on what it is like to engage in memory and mental time travel with and without words [62]. We begin to build a lexicon of the mechanisms in play and the patterns of thinking that are endemic across a variety of perceptual abilities. The broader platform provides an opportunity for alternative kinds of enquiry and thinking that may highlight the limitations of human thought (see [7]). Understanding what we cannot do and the discrepancies in our thinking may be a way forward.

In the final section, we offer three observations. The first concerns time. As alluded to in the Introduction physical time only appears to move in one direction, forwards. Although mental time travel moves bidirectionally, the time travelling patterns are different. When we reverse time in the mind's eye, we do not play it backwards in a continual fashion: we jump backwards and then play our imagining forwards again. This is in contrast to the gradual unfolding of events as we mentally travel forwards into a future that has not yet happened and may never happen in quite the way we envisage. As the White Queen remarked to Alice in Lewis Carroll's poignant tale *Alice through the looking glass*, 'it's a poor sort of memory that only works backwards' [63].

The second issue concerns the reconstructive nature of memory. We know that our memories shimmer and change each time we revisit them so why do we feel the need to assume that what we remember encapsulates what actually happened? In recalling events, we constantly make comparisons and in so doing make judgements about the present with regard to the past and our understanding of what has gone before. However, our memory cannot be an accurate reflection of what happened owing to the subjective nature of mental time travel. The very process of comparing the present

with the past, both defines the present and changes the past, and the process is on-going—like a train travelling a track it can never be in the same place twice. We are aware of the continuity of time, but only have the capacity to sample its passing. We chunk the unfolding moments into a series of snap shots, of events—it is the short hand of our thinking process, and then we search for ways to connect them, to join the missing dots. These ideas are poignantly expressed in the following quote from *The Moustachio Quartet* [61, pp. 72–73], in which the main protagonist is reflecting on how to make sense and reinterpret the series of unfolding events in his memory.

Years pass by and experiences, myriad moments, and un-summoned influences in various measures, impose themselves on the retina and in the memory of living persons. Memories, by virtue of their nature, will seem significant and often support earlier remembrances beyond themselves—or may even support experiences of memories yet to come. Long forgotten thoughts rise up again, when the need arises. What a rich tapestry of moments a person becomes over a lifetime! If nothing else, life is poignant.

Memories are markers. They can be isolated, but should not be. Intervening times are the real measure; they are stranger and more significant than the memories themselves. I tell myself they are notable and have been important. I tell myself that maybe the intervening times should become cherished more than the memories.

The space between two memories is where I remember real life to have taken place, where life was lived unadorned, devoid of flourish, hubris and ostentation. The true complexion of how times pass is to be found here—between two such points within a living memory. The measure can be quantified in easy stages—this was my former self, when young, and then I grew into this—each ensuing year a stepping-stone to the next new self, all individually recalled but seldom assessed, often forgotten and lost! A life is the space between one's earliest memory and where you find yourself now. That time that passes—what does it all mean? How does one quantify the significance, effect or complexion of so many years? Why does it have to make sense? Why do I feel it has to make sense?

It becomes a kind of madness to think of such things—and it is in any case impossible to quantify a life in such a way. Who can make sense of everything, as if attempting to see the thread and the line that time follows?

There is a second point being made here. The brain is not only subjective in its selectivity, it is also anticipatory: those imagined edges that belong to boundary extension are where we build convergence into our worlds and engage in developing responses to the ideas and treasured memories we see as pertinent. Such things are signposts to our futures and lie at the heart of creativity, although of course semantic memory plays a key role too in allowing prior knowledge

to be abstracted across many different experiences to structure and guide our current perceptions and future thoughts [16,64,65].

Finally, our need to collect mementoes and souvenirs of our experiences is of particular interest, an analysis of which may lead to some intriguing insights into the process of mental time travel. We might be referring to the postcards and other paraphernalia we select as 'aides de memoire', but more importantly, the objects that we use to define us, the cars we drive, the architecture and buildings we live in, and the cities we create for ourselves. All these things become physical extensions to our excursions into mental time travel, to the thinking process with which we project ourselves in time. They anchor fleeting moments within our living memories, to connect the missing dots, to convert the chunks into continuity and they cannot be forgotten or altered as easily as information that only exists as a memory. They take on the role of artefacts, evidence that can be viewed objectively, physical adjuncts to the mechanism by which we explore possibilities, order information and develop ideas.

So memory is more than just the projection of our self and other selves in space and time. It also has to take account of the physical world, that is to say the manner in which we interact and bond with naturally occurring and man-made materials. These things are the architecture of our lives, and define the process by which we share memories with others. It is for this reason that the city of Warapest becomes the living backdrop to the lives of the main protagonists in *The Moustachio Quartet*—much of what the characters think is defined by the environments in which they live and through which they move, and the objects and living things with which they associate.

Everything leads one to conjecture that memories are made for the future.

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Endnotes

¹A second reason is that we also have prospective memories, namely the ability to remember to do something in the future, e.g. making a mental note in the morning to buy a bottle of wine on the way home from work for a dinner party that evening.

²*The Man With The Seven Second Memory* (2005) directed by Jane Treays.

References

- Berger J. 1972 *Ways of seeing*. London, UK: Penguin.
- Tulving E. 1983 *Elements of episodic memory*. New York, NY: Oxford University Press.
- Tulving E. 2002 Episodic memory: from mind to brain. *Annu. Rev. Psychol.* **53**, 1–25. (doi:10.1146/annurev.psych.53.100901.135114)
- Tulving E. 2005 Episodic memory and auto-noesis: uniquely human? In *The missing link in cognition. Origins in self-reflective consciousness* (eds H Terrace, J Metcalfe), pp. 3–56. Oxford, UK: Oxford University Press.
- Wheeler MA. 2000 Episodic memory and auto-noetic awareness. In *The Oxford handbook of memory* (eds E Tulving, FIM Craik), pp. 597–625. Oxford, UK: Oxford University Press.
- Carroll L. 1965 *Alice's adventures in wonderland*. London, UK: Macmillan Press.
- Clayton NS, Wilkins CAP. In press. The creative navigator's compass: memory and perception—and how we know which way we are facing. *The Psychologist*.
- Craver CF, Kwan D, Steindam C, Rosenbaum SR. 2014 Individuals with episodic amnesia are not stuck in time. *Neuropsychologia* **57**, 191–195. (doi:10.1016/j.neuropsychologia.2014.03.004)
- Tulving E. 1972 Episodic and semantic memory. In *Organisation of memory* (eds E Tulving, W Donaldson), pp. 381–402. New York, NY: Academic Press.

10. Clayton NS, Dickinson A. 1998 Episodic-like memory during cache recovery by scrub jays. *Nature* **395**, 272–278. (doi:10.1038/26216)
11. Griffiths DP, Dickinson A, Clayton NS. 1999 Declarative and episodic memory: what can animals remember about their past? *Trends Cogn. Sci.* **3**, 74–80. (doi:10.1016/S1364-6613(98)01272-8)
12. Clayton NS, Bussey TJ, Dickinson A. 2003 Can animals recall the past and plan for the future? *Nat. Rev. Neurosci.* **4**, 685–691. (doi:10.1038/nrn1180)
13. Clayton NS. 2017 Episodic-like memory and mental time travel in animals. In *APA handbook of comparative psychology*, vol. 2 (ed. J Call), pp. 227–243. Washington, DC: American Psychological Association.
14. James W. 1890 *The principles of psychology*. New York, NY: Henry Holt and Company.
15. Irish M, Addis DR, Hodges J, Piquet O. 2012 Considering the role of semantic memory in episodic future thinking: evidence from semantic dementia. *Brain* **135**, 2178–2179. (doi:10.1093/brain/aws119)
16. Irish M, Piquet O. 2013 The pivotal role of semantic memory in remembering the past and imagining the future. *Front. Behav. Neurosci.* **1**, 27.
17. Michaelian K, Klein SB, Szpunar KS. 2016 *Seeing the future: theoretical perspectives on future-oriented mental time travel*. Oxford, UK: Oxford University Press.
18. Green J. 2006 *An abundance of Katherines*. New York, NY: Dutton Books for Young Readers.
19. Barlett F. 1932 *Remembering*. Cambridge, UK: Cambridge University Press.
20. Loftus E. 1974 Reconstruction of automobile destruction: example of interaction between language and memory. *J. Verb. Learn. Verb. Behav.* **13**, 585–589. (doi:10.1016/S0022-5371(74)80011-3)
21. Loftus E. 1975 Leading questions and eyewitness report. *Cogn. Psychol.* **7**, 560–572. (doi:10.1016/0010-0285(75)90023-7)
22. Loftus E. 2005 Planting misinformation in the human mind: a 30-year investigation of the malleability of memory. *Learn. Mem.* **12**, 361–366. (doi:10.1101/lm.94705)
23. Loftus EF, Miller DG, Burns HJ. 1978 Semantic integration of verbal information into a visual memory. *J. Exp. Psychol. Hum. Learn. Mem.* **4**, 19–31. (doi:10.1037/0278-7393.4.1.19)
24. Wilkins CAP. 2015 *The Moustachio Quartet: Mannikin*. Rutland, UK: Wind on the Wire Publishing.
25. Schacter DL, Addis DR, Buckner RL. 2007 Remembering the past to imagine the future: the prospective brain. *Nat. Rev. Neurosci.* **8**, 657–661. (doi:10.1038/nrn2213)
26. Schacter DL, Addis DR, Buckner RL. 2008 Episodic simulation of future events. Concepts, data and applications. *Ann. N.Y. Acad. Sci.* **1124**, 39–60. (doi:10.1196/annals.1440.001)
27. Schacter DL, Addis DR, Hassabis D, Martin VC, Spreng N, Szpunar KK. 2012 The future of memory: remembering, imagining and the brain. *Neuron* **76**, 677–694. (doi:10.1016/j.neuron.2012.11.001)
28. Clayton NS, Wilkins CAP. 2012 Imagination: the secret landscape. Being Human. See <http://www.beinghuman.org/article/imagination-secret-landscape>.
29. Gilbert D. 2006 *Stumbling on happiness*. New York, NY: Knopf.
30. Cheke LG, Simons JS, Clayton NS. 2016 Higher BMI is associated with episodic memory deficits in young adults. *Q. J. Exp. Psychol.* **69**, 2305–2316. (doi:10.1080/1740218.2015.1099163)
31. Laland K, Wilkins CAP, Clayton NS. 2015 The evolution of dance. *Curr. Biol.* **26**, R5–R9. (doi:10.1016/j.cub.2015.11.031)
32. Intraub H, Richardson M. 1989 Wide-angle memories of close-up scenes. *J. Exp. Psychol. Learn. Mem. Cogn.* **15**, 179–187. (doi:10.1037/0278-7393.15.2.179)
33. Gottesman CV, Intraub H. 2002 Surface construal and the mental representation of scenes. *J. Exp. Psychol. Hum. Percept. Perform.* **28**, 1–11. (doi:10.1037/0096-1523.28.3.589)
34. Gottesman CV, Intraub H. 2003 Constraints on spatial extrapolation in the mental representation of scenes. View-boundaries versus object boundaries. *Vis. Cogn.* **10**, 875–893. (doi:10.1080/13506280344000130)
35. Hassabis D, Maquire EA. 2007 Deconstructing episodic memory with construction. *Trends Cogn. Sci.* **11**, 299–306. (doi:10.1016/j.tics.2007.05.001)
36. Hassabis D, Kumaran D, Vann SD, Maguire EA. 2007 Patients with hippocampal amnesia cannot imagine new experiences. *Proc. Natl Acad. Sci. USA* **104**, 1726–1731. (doi:10.1073/pnas.0610561104)
37. Mullally SL, Intraub H, Maguire EA. 2012 Attenuated boundary extension produces paradoxical memory advantage in amnesic patients. *Curr. Biol.* **22**, 261–268. (doi:10.1016/j.cub.2012.01.001)
38. Corkin S. 2013 *Permanent present tense. The unforgettable life of the amnesic patient H. M.* New York, NY: Basic books.
39. Rosenbaum RS, Köhler S, Schacter DL, Moscovitch M, Westmacott R, Black SE, Gao F, Tulving E. 2005 The case of K.C.: contributions of a memory-impaired person to memory theory. *Neuropsychologia* **43**, 989–1021. (doi:10.1016/j.neuropsychologia.2004.10.007)
40. Klein SB, Loftus J, Kihlstrom JF. 2002 Memory and temporal experience: the effects of episodic memory loss on an amnesic patient's ability to remember the past and imagine the future. *Soc. Cogn.* **20**, 353–379. (doi:10.1521/soco.20.5.353.21125)
41. Wearing D. 2005 *Forever today: a memoir of love and amnesia*. London, UK: Corgi Press.
42. Wilkins CAP. 2017 *The Moustachio Quartet: Eissenstrom*. Rutland, UK: Wind on the Wire Publishing.
43. Suddendorf T, Corballis MC. 1997 Mental time travel and the evolution of the human mind. *Genet. Soc. Gen. Psychol. Monogr.* **123**, 133–167.
44. Corballis MC. 2013 Mental time travel: a case for evolutionary continuity. *Trends Cogn. Sci.* **17**, 5–6. (doi:10.1016/j.tics.2012.10.009)
45. Corballis MC. 2014 Mental time travel: how the mind escapes from the present. *Cosmology* **18**, 139–145. (doi:10.1515/9781400851492-008)
46. Clayton NS. 2014 EPS mid career award lecture. Ways of thinking: from crows to children and back again. *Q. J. Exp. Psychol.* **68**, 209–241. (doi:10.1080/17470218.2014.943673)
47. Moser MB, Rowland DC, Moser E. 2015 Place cells, grid cells, and memory. *Cold Spring Harb. Perspect. Med.* **7**, a021808. (doi:10.1101/cshperspect.a021808)
48. Thom JM, Clayton NS. 2016 Evolutionary perspectives on prospective cognition. In *Seeing the future: theoretical perspectives on future-oriented mental time travel* (eds K Michaelian, SB Klein, KK Szpunar), ch. 14, pp. 287–305. Oxford, UK: Oxford University Press.
49. Emery NJ, Clayton NS. 2004 The mentality of crows. Convergent evolution of intelligence in corvids and apes. *Science* **306**, 1903–1907. (doi:10.1126/science.1098410)
50. Emery NJ, Clayton NS. 2005 Evolution of brain and intelligence. *Curr. Biol.* **15**, R946–R950. (doi:10.1016/j.cub.2005.11.029)
51. de Kort SR, Dickinson A, Clayton NS. 2005 Retrospective cognition by food-caching western scrub-jays. *Learn. Motiv.* **36**, 159–176. (doi:10.1016/j.lmot.2005.02.008)
52. Dally JM, Emery NJ, Clayton NS. 2006 Food-caching western scrub-jays keep track of who was watching when. *Science* **312**, 1662–1665. (doi:10.1126/science.1126539)
53. Clayton NS, Yu KS, Dickinson A. 2003 Interacting cache memories: evidence of flexible memory use by scrub jays. *J. Exp. Psychol. Anim. Behav. Process* **29**, 14–22. (doi:10.1037/0097-7403.29.1.14)
54. Clayton NS, Dally JM, Gilbert JD, Dickinson A. 2005 Food caching by western scrub-jays (*Aphelocoma californica*) is sensitive to conditions at recovery. *J. Exp. Psychol. Anim. Behav. Process.* **31**, 115–124. (doi:10.1037/0097-7403.31.2.115)
55. Raby CR, Alexis DM, Dickinson A, Clayton NS. 2007 Planning for the future by western scrub-jays. *Nature* **445**, 919–921. (doi:10.1038/nature05575)
56. Emery NJ, Clayton NS. 2001 Effects of experience and social context on prospective caching strategies in scrub jays. *Nature* **414**, 443–446. (doi:10.1038/35106560)
57. Cheke LC, Clayton NS. 2012 Eurasian jays (*Garrulus glandarius*) overcome their current desires to anticipate two distinct future needs and plan for them appropriately. *Biol. Lett.* **8**, 171–175. (doi:10.1098/rsbl.2011.0909)
58. Correia SPC, Dickinson A, Clayton NS. 2007 Western scrub-jays (*Aphelocoma californica*) anticipate future needs independently of their current motivational

- state. *Curr. Biol.* **17**, 856–861. (doi:10.1016/j.cub.2007.03.063)
59. Cheke LC, Thom JM, Clayton NS. 2011 Prospective decision making in animals: a potential role for inter-temporal choice in the study of prospective cognition. In *Predictions in the brain* (ed. M Bar M), ch. 24, pp. 325–354. Oxford, UK: Oxford University Press.
60. Wilkins CAP. 2015 *The Moustachio Quartet: Count Zapik*. Rutland, UK: Wind on the Wire Publishing.
61. Wilkins CAP. 2015 *The Moustachio Quartet: Caruso*. Rutland, UK: Wind on the Wire Publishing.
62. Clayton NS, Wilkins CAP. 2016 Big picture: art is the process of memory. *The Psychologist* **29**, 15–16.
63. Carroll L. 1871 *Through the looking-glass, and what Alice found there*. London, UK: Macmillan Press.
64. Bubic A, Abraham A. 2014 Neurocognitive bases of future perception. *Rev. Psychol.* **21**, 3–15.
65. Wilkins CAP. 2008 *The creatures in the night*. Dingley, UK: Dingley Press.