

Evolutionary economics of mental time travel?

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What is the function of our capacity for ‘mental time travel’? Evolutionary considerations suggest that vivid memory and imaginative foresight may be crucial cognitive devices for human decision making. Our emotional engagement with past or future events gives them great motivational force, which may counter a natural tendency towards time discounting and impulsive, opportunistic behavior. In this view, whereas simple episodic memory provides us with a store of relevant, case-based information to guide decisions, mental time travel nudges us towards more restrained choices, which in the long term are advantageous, especially so given human dependence on cooperation and coordination.

Memory and imagination as decision-making processes

Many animals seem to have a capacity for some form of episodic recall, retrieving specific information about the ‘what, where and when’ of past experiences ([1,2], but see Ref. [3] for limits to such claims). Humans (and perhaps other animals) also engage in what has been called ‘mental time travel’ (MTT), a form of recall that allows one to re-experience, albeit in an attenuated form, situations previously encountered [4,5]. There is converging evidence that MTT is crucial to human decision making. Here, I offer an explanation for that connection. MTT, in the view proposed here, provides a motivational ‘brake’ that counters natural dispositions towards opportunistic, short-termist, ‘myopic’ decision making.

Under what conditions would natural selection favor the appearance of a capacity to re-experience the past and experience the future? There is surprisingly little literature to address these questions, mostly because few psychologists adopt a functional view of memory systems (but see Refs [6–8]). Recently, several independent proposals have been made for a functional account (see Box 1). Various aspects of human cognitive functioning seem to derive increased efficiency from knowledge of past episodes. In these functional accounts episodic memory and counterfactual imagination are two aspects of the same capacity to engage in off-line inferences as an aid to present decision making, for instance, by maintaining a store of exemplars against which to compare present situations and select the most beneficial course of action [4,9]. This would suggest that MTT is a recent adaptation whose emergence is connected with the sudden increase in behavioral variety and

flexibility that prepared the transition to *Homo ergaster* and *sapiens* [10,11]. This is consistent with the computational connections between MTT and other, probably recent, high-level cognitive functions such as self-knowledge and metarepresentations [12].

Why add MTT to episodic memory or imagination?

Functional models so far explain only why we are able to entertain information about past or possible situations, not why we also actually experience these situations. The reason for evolving MTT, as opposed to mere what-where-when knowledge, must lie in mental activity that is present in the former but not in the latter. In MTT, visual and auditory imagery combine with activation of emotional circuitry to create ersatz experience [13]. As Martin Conway and others have pointed out, autobiographical memory makes use of ‘phenomenological records’, that is, fragments of sensory perceptual–conceptual–affective material that was present in working memory during a short period of time (usually within the bound of one short segment of goal-directed activity). Entertaining a memory means combining these fairly low-level representations with autobiographical facts from semantic memory [14].

Imagery and emotion are especially salient in involuntary memories – which constitute most occurrences of episodic recollection – yet for practical reasons are less studied than cued, controlled retrieval of memories. Involuntary memories are generally more specific in content than deliberately retrieved ones. Also, they have a more intense emotional tenor and have a greater impact on current mood. The general bias towards positive memories observed in deliberate recall is reversed with involuntary recollection [15].

Emotion is crucial to the intuition that an event represented actually occurred [16]. Neuroimaging confirms that the recollection of specific situations triggers not just limbic activity but also the recreation of specific internal or visceral states associated with the original situation [17]. The emotional component of recollection is not a controlled process, and it often clashes with current goals. This is true of positive memories but even more of negative ones [18].

These features all apply to forecasting and imagination as well. That forecasting and recall are part of the same function is an evolutionary hypothesis [4], now supported by both behavioral evidence [19] and neuroimaging, showing that imagining future circumstances modulates activation of the same cortical networks as remembering past episodes [20,21]. Both future and past imagery of one’s own experience are neurally distinct from imagining another

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Box 1. Possible functions of MTT

Various functional accounts have been put forward, placing emphasis on distinct contributions of episodic recall to ongoing behavior (Table I).

Table I. Possible functions of episodic recall

Possible function	Motivation and evolutionary pressure
Foresight and flexible planning [9]	Episodes provide a store of possible scenarios whose combination allows sophisticated foresight and, therefore, flexible planning.
Case-based inferences [9] and scope syntax [60]	Episodic memory allows judgment of current situation on the basis of its similarity to previously encountered ones. Expertise in, for example, social interaction requires case-based reasoning rather than (or as well as) rule-governed inferences.
Hindsight [61]	Episodes include information about currently irrelevant features of a situation that subsequently may become relevant in view of changed circumstances.
Economic vigilance [28] and accountability [62]	A form of hindsight. Detailed information about past social interactions allows us to judge who is a reliable economic partner. Also, that information may become crucial in making judgments about people's reliability as coalition partners.
Epistemic vigilance [63]	Humans depend on information conveyed by conspecifics, so they need evaluation of other agents' epistemic reliability. To judge whether people's utterances are credible, one must keep a detailed record of communicative events.

Note that these are all plausible evolutionary scenarios for the emergence of detailed episodic stores from which detailed, originally irrelevant information can be retrieved. But MTT is more than just episodic recall (see main text). It is not yet clear whether any of the functions described above would require the actual re-experiencing of past situations accompanied by mental imagery and emotional engagement.

person in similar circumstances [22]. The integration of memory and imagination also is supported by the neuropsychological evidence because retrograde amnesia is accompanied by a symmetrical deficit in imagination for future events [23,24].

To sum up, a crucial aspect of MTT seems to be the inescapable experience of relevant emotions slightly biased towards the negative, which are independent of the subject's current goals. These features are puzzling if the function of MTT is to provide an accurate store of past events or to contribute to the achievement of the person's current goals. But, they may be functional precisely to the extent that they do not fit current goals.

Cooperation is difficult, restraint is adaptive

Cooperation between non-genetically related individuals, as well as coordinated action involving many agents, are rare in nature and ubiquitous among humans (see Refs [25,26] for surveys and models). Humans are also special in that they engage in nonopportunistic or other-regarding behaviors in which they benefit others without clear return in terms of their own fitness, like giving tips in restaurants that one will not visit again or helping perfect strangers find their way [27]. A wealth of data from experimental economics suggest that other-regarding tendencies are general and stable [28] and that they operate even in supposedly rational markets [29] and, of course, in ordinary social interaction.

One of the major hurdles for cooperation is that its benefits are in the future and the sacrifices it entails are (in general) to be made right away. Similarly, failing to cooperate may bring about negative outcomes, but that is also in the future. Now a general psychological principle is that later counts for less than now; in other words humans, like all other animals, engage in time-discounting (see Box 2). Discounting is adaptive because rewards only impinge on fitness if they do occur and their probability diminishes as they recede further into the future [30].

But cooperation does occur, which means that the motivation to act opportunistically and myopically, on the basis of immediate rewards, can be opposed. There

are, indeed, many ways to escape temptation, such as by putting social, physical or legal obstacles in the path of one's own goals (see Box 3). Obstacles to opportunistic choices also may be internal to the agent in the form of specific mental states. Robert Frank, for instance, has argued that moral feelings may provide rewards that offset the temptation of opportunistic action [27]. As we consider prospective courses of action, impulsive, opportunistic choices (e.g. mug this old lady, take advantage of one's friends) are tempting because their positive outcome is immediate, whereas their negative consequences (e.g. jail, loss of friends) are time discounted. But moral feelings (e.g. disgust at the idea of mugging people, guilt at the prospect of being a bad friend) provide an immediate negative reward that nudges us away from these choices [31].

Imagined and recalled situations as counter-rewards

Several properties of MTT suggest that it may also play this role of a countermotivation device that offsets the effects of time discounting: (i) episodic recall and imagined futures are often noncontrolled – a situation or a plan can trigger specific time-travel experience without the need for deliberate retrieval or construction; (ii) once triggered, they generally activate emotional circuitry, leading to immediate rewards; (iii) these emotional rewards themselves are outside cognitive control and (iv) the emotions are appropriate given the situation recalled or imagined.

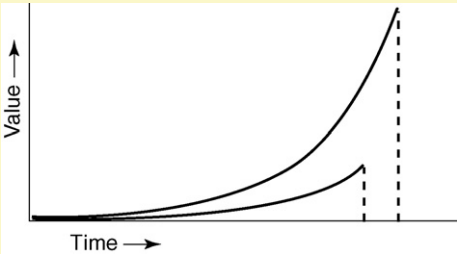
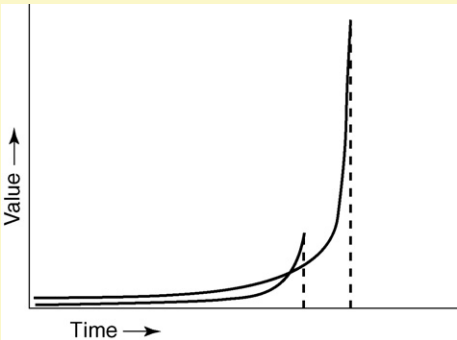
In this view memory and imagination may play the role of a brake on impulsiveness or a boost on patience by associating our plans with non-controlled, non-opportunistic rewards, negative or positive (see Figure 1).

To reprise the above example, a tempting antisocial plan (e.g. taking advantage of a friend) may remain tempting as long as previous (and possible future) consequences of that course of action are blunted by time discounting, but that effect would be dampened when these consequences are (by virtue of memory and forecasting) keenly felt as present emotions. Conversely, the effort required to learn a musical instrument may deter one from sustained practice, but that effect will be checked if the imagined consequences (the pleasure to play, the reputation gain) are felt right now.

Box 2. Time discounting and impulsiveness

All animals discount future rewards [30]. Rational-choice models prescribe a normative exponential discount (left), but most animals actually use a different discount curve based on a hyperbolic function to compute present utility of future rewards (right) (Table I).

Table I. Two different models of discounting

Exponential discounting	Hyperbolic discounting
Normative: what economic agents should do under assumptions of rational choice theory, e.g. full knowledge, no computational load, etc. [64]	Descriptive: what human and animal agents actually do when considering future rewards, given uncertainty, limited computational power, etc. [65]
Typical equation: $now = then * (1 - rate)^{delay} \quad (I)$	Typical equation: $now = \frac{then}{(rate * delay)} \quad (II)$
In Equations I and II, 'now' is the present utility of the reward, 'then' is what the reward will be worth when it occurs, 'delay' is the time to wait before getting the reward and 'rate' is the discount rate or 'impatience factor'. In humans the actual discount rate is sensitive to amount of reward [66], age [67] and personality variables [68].	
Preference ordering is stable	Preferences may be reversed
	
A consequence of hyperbolic discounting is that distinct preferences, which should always remain ordered the same way (left), may be reversed (right) when one gets close to the time of gratification. This leads agents to prefer smaller-sooner (SS) rewards to a larger-later (LL) ones. This dynamic is present in many familiar behaviors. Maintaining a good figure seems more important than eating cake until the cake appears on the table.	
Many types of impulsive, short-termist behaviors are triggered by this property of the discount curve, from gambling to drug dependence or other risky behaviors. The motivational strength of short-term preference reversal is made greater in many 'impulsive' subjects by distorted time perception [69].	
Given the frequent occurrence of time-based preference reversals, agents need an additional source of motivation to approximate the 'rational' curve (left) with stable preferences.	

That decision making is crucially dependent on emotion and prospective emotion is not really contentious [32] and is made more salient by the many instances of ‘affect

as information’ [33]. Emotions connected to episodes constitute self-persuasion devices [34], especially when there is no clear way to explain away the emotion and when it comes from one’s own experience [35]. But the point here is that some emotions are adaptive-motivation devices to the extent that they are not altogether consistent with our current goals.

Box 3. Defeating impulsiveness: commitment and emotion

Although they discount the future (Box 2), agents can override their tendency to choose smaller-sooner rewards over larger-later ones. They can use precommitment to force themselves into a less impulsive course of action [70]. Typically, this requires some ‘commitment device’ that reduces one’s own options. Ulysses, for instance, asked his sailors to tie him to the mast, lest he succumb to the siren’s enticement. Taking an oath of solidarity is another such device. It makes subsequent defection costly in terms of reputation. In this sense social disapproval helps overcome short-termism.

Precommitment can take many forms, including ‘eliminating options, imposing costs, setting up rewards, creating delays, changing preferences, investing in bargaining power, inducing ignorance, inducing passion’ [71]. But these are cases in which the agents (i) know that their preferences may change and lead them to impulsive choices, and (ii) can avail themselves of a commitment device (Ulysses had sailors to tie his hands) or are vulnerable to social pressure. As Ainslie points out, in many situations there are no such devices [65]. Also, people’s sensitivity to external pressure may vary, giving an opportunistic advantage to those less swayed by reputation considerations. All this suggests that non-opportunistic behavior will often require some internal source of countermotivation against impulsive choices: feelings, emotions and other internal variables that affect motivation.

Counter-reward function explains some features of time travel

In this view MTT can act as a calibration device by triggering emotional rewards that accurately reflect the emotional impact of the hypothetical or past situation and are immediate and, therefore, bypass the usual discounting of future consequences of actions. The conjecture, obviously, is worth considering only if it makes sense of a large amount of evidence and suggests new lines of inquiry.

The calibration model would predict that differences in the availability or salience of episodic memories and hypotheticals would result in differences in impulsivity. Unfortunately, there is virtually no study of individual differences in these aspects of episodic memory or counterfactual thinking. However, the neuropsychological and psychiatric literatures, dealing with large deviations from

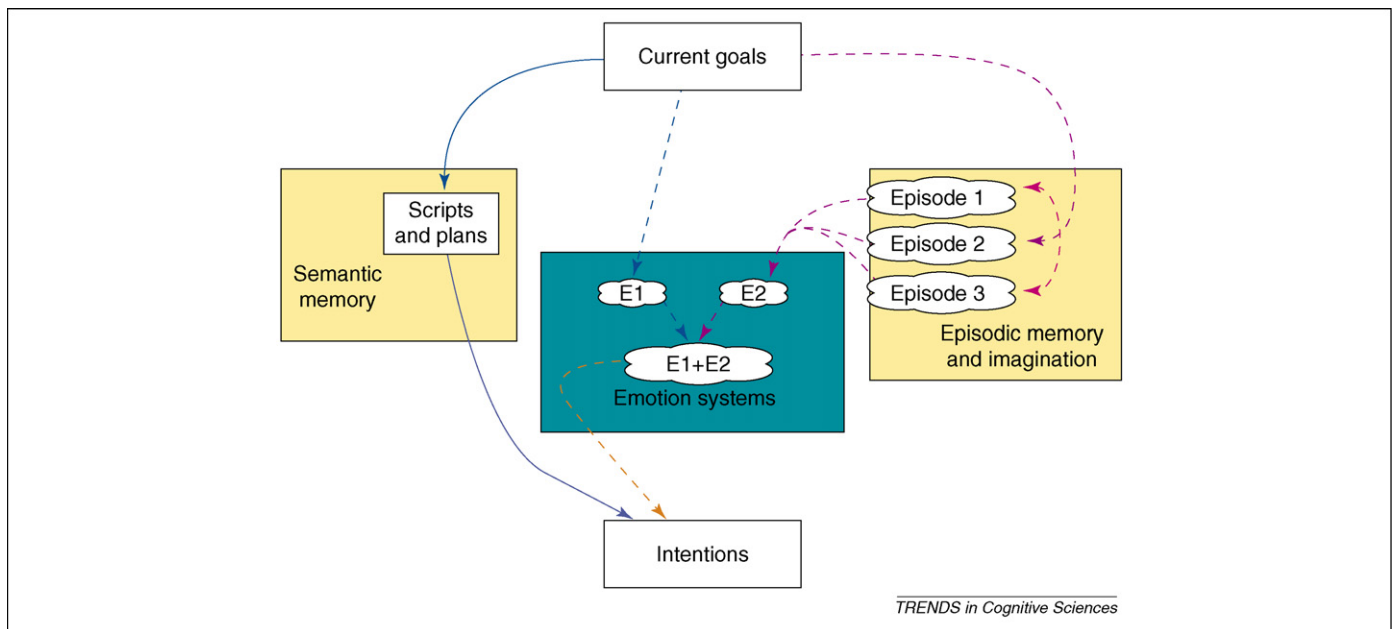


Figure 1. A simplified schema of memory and imagination involvement in decision making. Solid lines represent controlled processes and dotted lines, non-controlled processes. Colored boxes represent systems and white boxes, their products.

the typical cognitive profile, are congruent with the model. Amnesic patients seem to be more vulnerable to tempting but self-defeating strategies, e.g. when playing the Iowa Gambling Task [36]. Further effects of memory loss on decision making have not been studied in any depth, however, and may be masked by most patients' restricted lifestyles. Conditions such as Borderline Personality Disorder, characterized by extreme instability in personal choices, are accompanied by specific memory biases in autobiographical recall [37,38] as well as poor imagination for action outcomes [39].

In terms of typical memory processes, the calibration model requires that memories and fantasies nudge us in the right direction, as it were. For one thing, memory of past negative emotions should not be revised in the light of current goals. Indeed, in contrast with a variety of memory-distortion effects (see survey in Ref. [40]), people are rather accurate as regards the emotional valence of past situations. True, mood-congruence effects or attitude revision can affect the selection of memories but not their valence. In a series of naturalistic studies, Levine and colleagues only found evidence for very limited distortion in a small minority of subjects [41,42].

Memory for emotions, then, does not align with our current goals. This is striking in the common phenomenon of rumination, the unwanted but persistent activation of thoughts concerning an unpleasant past situation [43]. The mirror image of rumination is the set of affective forecasting ‘biases’ discovered by Gilbert and colleagues [44–46]. When considering possible future circumstances, people tend to exaggerate (relative to what actually happens) the negative emotional impact on their everyday lives of such events as the loss of their job or the breakup of a romantic relationship. In this way the imagined future situation triggers emotional experience that goes against the natural discounting of future negative outcomes. Affective forecasting in this sense

may be part of an efficient choice-calibration process, especially because it seems to make people more loss averse [47,48].

Functional models

Social interaction is a highly complex affair in which no two situations are ever identical, and identical pieces of information yield diametrical inferences depending on contextually appropriate memory activation, which is why conditioning and other general learning strategies seem insufficient. As one may expect a species with extensive cooperation possesses a unique suite of relevant cognitive capacities (e.g. memory for social situations [49] for the identity of the agents involved) as well as motivations (e.g. for cooperating and avoiding cheaters [50,51]). Obviously, in this, like in other domains, natural selection does not equip agents with a representation of fitness cost benefits but with proximate concepts and motivations that on average, in ancestral-like conditions, lead to increased fitness [52]. Although fitness is the only currency of adaptation, these motivational proxies are the only proximate causes of actual behavior.

Time travel may be functional to the extent that it provides emotions that bypass current goals as well as time discounting and, therefore, provide us with immediate counter-rewards against opportunistic motivation. The model goes against common intuitions of ‘cool cognition’ as adaptive and ‘hot emotion’ as irrational, a model widespread in traditional decision-making paradigms [53]

Now one may find such a model unduly complex, relying, as it does, on two (or more) sources of motivation instead of stipulating an integrated cost-benefit computation that yields the appropriate utility curves. This complexity is, in fact, common in non-normative, empirically based models of decision making that integrate evidence from domain-specific choices, variation in personality profiles, and clinical evidence for pathological preference sets

[30,54,55]. Dual (or n-tuple, with $n > 2$) models are congruent with the neurophysiological evidence that dissociates emotional from non-emotional components of choice [56,57] but also different circuitry for positive and negative rewards [58] and, perhaps, further fractionation [59].

The merit of such a functional hypothesis is to account for otherwise puzzling features of MTT, for example, that it is frequently involuntary, goal incongruent, emotion laden and uncontrollable. The validity of the hypothesis can be assessed only once we have better evidence to address the empirical questions it suggests; for example, are there individual differences in episodic recall and affective engagement in memory? Are there similar differences in terms of imaginative engagement? Do these differences correlate with impulsiveness versus patience? And, finally, what are the precise neuroeconomics of immediate reward, planned reward and emotional commitment?

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