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Mental time travel, memory and the social learning strategies tournament

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ABSTRACT

The social learning strategies tournament was an open computer-based tournament investigating the best way to learn in a changing environment. Here we present an analysis of the impact of memory on the ability of strategies entered into the social learning strategies tournament (Rendell, Boyd, et al., 2010) to modify their own behavior to suit a changing environment. The tournament showed that a strategy's ability to remember the past and to predict the future were both key to its success. The possibility that a strategy needs to engage in an approximation of 'mental time travel' to succeed in the tournament strongly implies that investment in randomly timed social learning is not enough to guarantee success. A strategy must use social learning strategically with reference to both predicted future environmental states and past environmental states. We examine the two most successful strategies (DiscountMachine and Intergeneration) in terms of their use of memory and discuss the impact of their complex memory use on their ability to time learning moves strategically and track environmental change. The tournament suggests that the human capacity for mental time travel may have improved the efficiency of social learning and allowed humans to invest in more sophisticated social learning than is seen elsewhere in the animal kingdom.

Learning and memory are two clearly related concepts, with the ability to learn resting on the ability to form memories. Learning is generally defined as an extended and long-term process whereby individuals can alter their behavior and state of knowledge, based, in part, on their previous experiences. As the neural substrate for learning, memory can be considered to be a description of how changes in knowledge state, motor abilities or behavioral repertoire are encoded in the brain and later retrieved to form the basis of behavioral changes (Richter, 1966). It is therefore not a huge leap in imagination to glean information about memory use from models of learning. Here we do that, paying special attention to the role of memory in the learning exhibited in the social learning strategies tournament (Rendell, Boyd, et al., 2010; Rendell et al., 2011).

Social learning is learning that is facilitated by observation of, or interaction with other individuals or their products (Heyes, 1994). The idea that social learning was a cheap and efficient form of learning in which individuals need not encounter the dangers or time-consuming costs associated with individual learning was generally accepted until, in 1988, an anthropologist, Alan Rogers, proposed what came to be known as Rogers' paradox. Rogers developed a simple mathematical model which established that agents in a population who engaged in unbiased (random) social learning were, at equilibrium, no fitter than agents who engaged in asocial learning (Rogers, 1988; Enquist, Eriksson, & Ghirlanda, 2007; Rendell, Fogarty,

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& Laland, 2010). Though not strictly speaking a paradox (rather, a counter-intuitive consequence of frequency-dependent selection), this result was viewed as surprising (hence 'Rogers' paradox'), since social learning underpins cultural learning, and culture, in turn, is widely thought to have increased human fitness substantially.

The notion that social learning cannot generally be random if it is to be adaptive led to interest in the strategic use of social learning: carefully choosing when to learn and from whom (Boyd & Richerson, 1985; Laland, 2004). Social learning strategies involving a mixture of social and asocial learning were widely discussed in cultural evolution (Boyd & Richerson, 1985; Enquist et al., 2007; Feldman, Aoki, & Kumm, 1996; Henrich & McElreath, 2003; Rogers, 1988) and animal social learning (Galef & Laland, 2005; Kendal, Coolen, van Bergen, & Laland, 2005; Laland, 2004) literatures. However, the sheer number of possible strategies posed a challenge to the field and only one or two strategies could be examined at a time (e.g. Enquist et al., 2007; Rendell, Fogarty, et al., 2010).

The 'social learning strategies tournament' was a way to examine the relative merits of a large number of strategies in one standard simulation environment. The organisers invited researchers to take part in a competition where they would submit social learning strategies, and these strategies would compete against each other in a simulation environment. The tournament attracted 104 entries from 14 countries and a myriad of academic disciplines (Rendell, Boyd, et al., 2010). The contests involved 100 agents who could learn about a possible 100 acts, each with a payoff drawn from an exponential distribution, which changed with the environment at a rate p_c. Although the opportunity for advancement in the study of social learning was the original focus of the tournament, it has become clear that the large number of strategies submitted to the tournament coupled with the strictly controlled simulation environment has yielded information on a variety of topics, including optimal use of social learning, optimal timing of social learning moves, the type of culture strategies can produce, and the effect of social learning on the persistence of knowledge and culture (Rendell, Boyd, et al., 2010; Rendell et al., 2011).

The submitted strategies varied substantially in their performance, affected by a number of factors, the majority of which we will not consider here (but see Rendell, Boyd, et al., 2010). However, the winning strategy, called DiscountMachine and submitted by Dan Cownden and Tim Lillicrap, appeared to enhance its performance through a simple form of 'mental time travel', as did several other successful strategies. Here we discuss what this use of 'mental time travel' by a number of the strategies submitted to the tournament might imply about memory in a social learning context.

Typical definitions of mental time travel involve 'episodic memory' of the past, consideration of the future and an understanding of how these relate to the self (Dudai & Carruthers, 2005; Suddendorf & Corballis, 1997; Tulving, 1983). Thus, mental time travel involves subjective reconstruction or construction of past or future events. In the case of humans, researchers can clearly see and demonstrate the presence of episodic memory and future planning. Conversely, in the case of animals, who are unable to verbalize their experiences of memory, researchers must rely on their actions to draw conclusions about the content of their memories and the mechanisms by which they access that content. This has led to the use of the terms 'episodic-like memory', 'future planning' or '*what, where, when*' (*www*) memory in discussions of animal mental time travel (Clayton & Dickinson, 1998; Clayton, Bussey, Emery, & Dickinson, 2003; Raby, Alexis, Dickinson, & Clayton, 2007).

The importance of mental time travel and its specificity to humans has been hotly debated for some years (Clayton et al., 2003; Suddendorf & Busby, 2003; Suddendorf & Corballis, 1997). Even in the midst of this debate, it is useful and interesting to examine the effects of memory, and future projection, on the success of individuals in a changing environment. Here we take a general definition of 'mental time travel' and apply it to the tournament strategies. Our intention is to elucidate the effect of memory use on the success, or otherwise, of individuals using these strategies. The tournament provides us with a unique opportunity to examine the effects of different memory use capabilities on evolutionary success in a standardized and simplified environment.

When discussing memory in computer models such as the tournament, we encounter a series of definitional problems that need addressing before we proceed. Each agent in the tournament had full access to its past moves and the results of those moves. In essence, our agents had access to what Tulving (1983) called 'memory as a warehouse'. Therefore, if they chose to, they could remember every move they made from the moment of their birth to their last simulation round. However our agents did not have access to the computer memory containing information about other agents' histories or environmental parameters (Rendell, Boyd, et al., 2010 S.O.M.).

The agents in our tournament are incapable of the type of complex mental task, vividly reliving the past and imagining the future, described above, making it challenging to define the type of memory to which agents in our model have access. What we are seeing when we look at our computer agents is how the information encoded in their simple memories can be used (for instance, by weighting more recent learning more heavily than older knowledge, or making predictions into the future about the likely success of cultural behavior), and what effect the extent to which they access this information can have on the agent's success. We are narrowly focussing on personal *www* memory, but since there is no spatial context in our simulations, the 'where' aspect is ignored. The difference between mental time travel and *www* memory is really a difference in subjective experience, say the difference between remembering the time, date and location of your birth and being able to mentally relive the event itself (Suddendorf & Busby, 2003). Thus we are interested in the content of memories rather than the subjective experience of them. This is true for many computer models of learning, which focus primarily on what information is retained and the origins of the information – what individuals learn from whom. As a result, the models are generally agnostic as to the exact memory mechanisms used to encode the information. It is therefore possible for us to discuss the effects of learning and memory without defining the memory mechanisms in detail.