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## Intertemporal Choice

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### Introduction

A Clark's nutcracker (*Nucifraga columbiana*) flies to the top of a pine tree and selects one of the many cones. She twists and pecks at the stem until the cone breaks free from the branch and, with one foot, holds the cone in the crotch of a branch. She then repeatedly hammers her long bill in between the scales of the cone. After forcing out one of the seeds, she tips her head back a bit, clicks the seed in her bill a few times, and closes her bill. A few minutes later, the shredded cone drops to the snow, the nutcracker having extracted several dozen seeds. Each time she closes her bill, the nutcracker makes a choice: she either swallows the seed or places it in a small pouch of skin under her tongue. The seeds placed in her pouch are destined for a site several kilometers away, where she buries them under a bit of dirt or leaf litter. In the autumn, she may bury 33,000 seeds in this manner, only to return to uncover them a few months later during the harsh mountain winter. This form of food storing or caching typifies an interesting and wide-ranging set of decisions faced by animals: intertemporal choices.

The term "intertemporal" choice refers to decisions in which the benefits associated with different outcomes occur at different times. For instance, for each seed, the nutcracker must choose between eating it now versus waiting to consume it in the winter. Often, there exists a trade-off between the size of the benefit and the cost (time delay), such that larger benefits accrue after longer delays. Thus, the decisions of interest are between obtaining immediate or short-term rewards and investing in a grander future.

### Intertemporal Choice in the Wild

Although not usually framed in this way, many decisions that animals face involve a temporal trade-off. The life history trade-off of growth versus reproduction offers an example of balancing the immediate, competitive benefits of growing larger with the delayed benefits of investing in offspring. Even plants and other organisms face these kinds of temporal trade-offs. Although these provide perfectly reasonable examples of temporal trade-offs, most work in this area has explored more active intertemporal choice decisions that often reflect the particular ecology of the individual species. The food caching example provides a nice illustration of species-specific choices between immediate and delayed

consumption in a foraging context. Caching provides a remarkable example of intertemporal choice because of the long delay until food recovery. Many other foraging-based intertemporal choices involve rather short delays: for instance, continuing feeding in the current food patch versus moving on to another patch. In fact, patch exploitation offers a classic example of intertemporal choice from behavioral ecology that is well studied both theoretically and empirically.

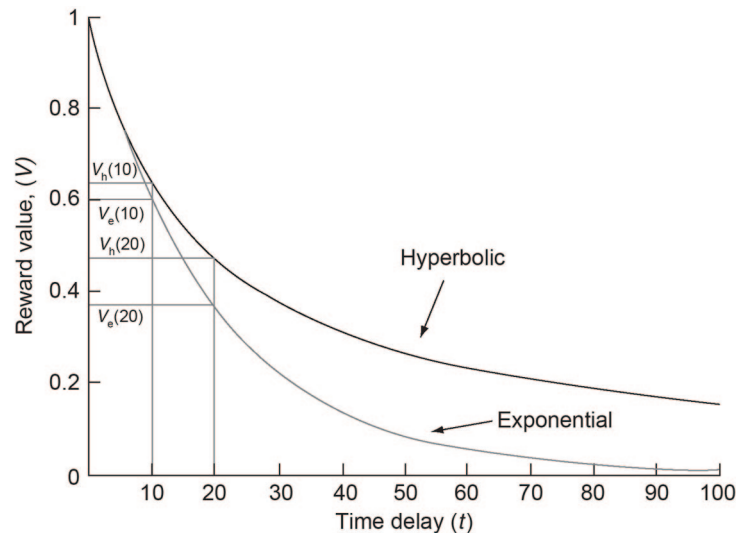
Imagine a bird eating berries from a bush. Every berry consumed depletes the patch and increases the average time required to find the next berry. When should the bird stop searching in that patch (after all, there may be no more berries in the bush) and move to the next bush? Staying too long can waste time better used in searching for food elsewhere. Leaving too early can waste opportunities to obtain a quick meal. Optimal foraging theory predicts a simple patch-leaving rule when patches are similar: leave when the foraging rate in the patch drops below the average foraging rate in the environment. We can calculate this foraging rate:

$$\frac{A}{\tau + t + h} \quad [1]$$

where  $A$  represents the amount of food,  $\tau$  represents the time required to travel between patches,  $t$  represents the delay to finding food within a patch, and  $h$  represents the time required to process and consume the food. Maximizing this foraging rate results in an optimal solution to the question of intertemporal choice in the patch-foraging situation.

Foraging decisions often involve the temporal trade-offs characterizing intertemporal choices, from patch foraging to caching to decide between a smaller, easier-to-process food item and a larger, more difficult one. Yet intertemporal choice extends far beyond foraging. Returning to the category of life history examples, parental investment exemplifies an important temporal tradeoff. Investment in current offspring reduces potential investment in future offspring. How should a parent distribute investment over time? Also, mating decisions have a critical temporal component—along the lines of choosing between Mr. Right and Mr. Right Now. Should an individual accept the currently available mate or continue looking for a higher quality mate?

Cooperative situations may also involve intertemporal choices. Reciprocal altruism, for instance, requires that animals trade the immediate benefits of defection



**Figure 1.** Models of temporal discounting describe how the subjective value of a reward at the present time decreases with the delay to receiving that reward. The exponential model promoted by economists predicts that the rate of discounting is constant over time, whereas, the hyperbolic model promoted by psychologists predicts a decreasing rate of discounting. As an example, we can compare the difference in values for the two models over two time frames: from  $t = 0$  to  $t = 10$  and from  $t = 10$  to  $t = 20$ . At  $t = 0$ , both the hyperbolic model ( $V_h(0)$ ) and the exponential model ( $V_e(0)$ ) start with a value of 1. At  $t = 10$ ,  $V_h(10) = 0.65$  and  $V_e(10) = 0.61$ , thus the hyperbolic value decreased by 0.35 in 10 time units, and the exponential value decreased by 0.39. At  $t = 20$ , however,  $V_h(20) = 0.48$  and  $V_e(20) = 0.37$ . The relative decrease from  $t = 10$  is 0.26 for hyperbolic and again 0.39 for exponential. Thus, the decrease remained the same for exponential value but diminished for hyperbolic value.

against the delayed benefits of reciprocated cooperation. Clearly, many behaviors fall under the umbrella of intertemporal choices, although they are not typically analyzed with this framework. Even when viewing these decisions as intertemporal choices, researchers use various terms such as temporal discounting, self-control, impulsivity, patience, and delayed gratification. Because of the broad nature of intertemporal choices, they have attracted the attention of many disciplines, including economics and psychology, as well as biology.

### Economics of Intertemporal Choice

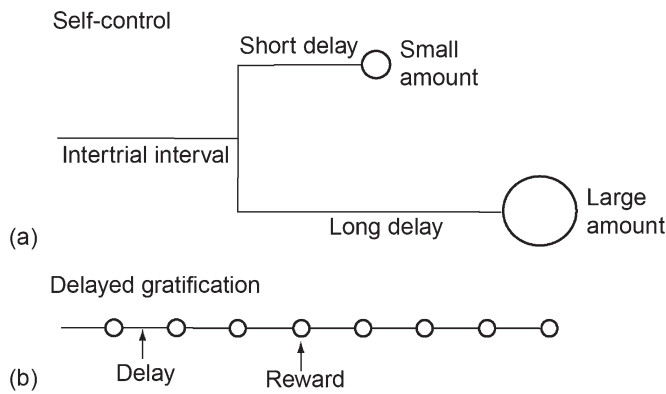
One of the first disciplines to investigate intertemporal choice was economics. Economists study the consumption of goods and services; thus, they want to know how agents manage streams of benefits that accrue over time. How do they balance the consumption of a small amount of a commodity now compared to a larger amount later? The economic perspective focuses on a “rational” account of how agents should respond to choices over time. That is, assuming that agents have all information about the goods, what response provides the optimal return? Economists noticed that, when given a choice between the same benefit immediately or in the future (say, one dollar now vs. in 20 years), people preferred the immediate payoff. This effect suggests that people temporally discount or devalue future payoffs. In other words, a delay reduces the subjective value of receiving a benefit. Why should we discount the future?

Economic theory proposes a number of reasons to discount the future. First, inflation literally makes money less valuable. One dollar will buy more lollipops today than it will after 20 years. Also, individuals can invest currently available benefits. That is, there are opportunity costs associated with not being able to use or invest benefits that are locked away during the delay. Investing one dollar now will yield much more in 20 years than one dollar. Finally, the future is uncertain. A bird in the hand is worth three in the bush because the three in the bush may never be in hand. Future rewards run the risk of not being realized; instead, some force may interrupt their consumption.

These three reasons for discounting are related, and economists have developed a model to account for intertemporal choice. In this model, each option yields a present value:

$$V = \delta^t A \quad [2]$$

where  $\delta$  represents a discount factor and  $t$  represents the delay to receiving reward amount  $A$ . The discount factor  $\delta$  accounts for the remaining value after a single unit of delay (thus, from  $\delta$  we can calculate the rate of discounting—the proportional rate of decrease in value). This “exponential discounting model” has a special feature: the rate of discounting remains constant across the delay (Figure 1). So, a reward delayed 1 day after another reward is available will lose the same value if the first reward is available today or in a year. In other words, value decreases at the same rate across time.



**Figure 2.** (a) The most frequently used method to investigate intertemporal choice in pigeons and rats is the self-control paradigm. In this technique, subjects experience an intertrial interval in which nothing happens. Following this interval, subjects choose between receiving a small amount of food after a short delay and a large amount of food after a long delay. After consuming the food, another intertrial interval begins. (b) In the delayed gratification paradigm, a certain amount of food accumulates at fixed rate, say, one food reward per 10 s. Interrupting the stream of food results in stopping the accumulation of rewards.

This constant rate of discounting makes sense when organisms discount because of future uncertainty, that is, when the risk of interruption makes a delayed reward less valuable. If random events interrupt the receipt of delayed payoffs, then decision makers face a constant probability of loss, making discounting to match the environmental loss rate beneficial. Thus, discounting may closely relate to uncertainty and risk.

### Psychology of Intertemporal Choice

For decades, psychologists have acted as the fly in the ointment for the elegant economic models of decision making. The psychological approach focuses on describing the actual behavior of decision makers rather than creating models of omniscient, godlike agents. In many cases, the models do not hold up well—behavior deviates substantially from the rational predictions. So, how can we measure the temporal preferences of animals to test the models?

#### Experimental Methods

Animal experiments often use the “self-control” paradigm to explore intertemporal choice (Figure 2(a)). This typically involves offering a subject the choice between a smaller amount of food after a shorter delay (smaller-sooner option) and a larger amount of food available after a longer delay (larger-later option). Subjects often start with a fixed set of options, then the experimenter adjusts either the long delay or the larger amount to titrate an indifference point, that

is, to find a pair of options between which the subjects choose equally. For example, a subject may first face the choice between two food items available immediately and six food items available immediately. Assuming that the subject prefers the larger amount, a one-second delay is added to the larger option. The experimenter will continue to add one second increments to the large amount until the subject chooses the two immediate food items as often as she chooses the six delayed items. This indifference point then indicates how long a subject will wait for three times as much food. Many psychologists interpret these data as a kind of discounting: the delayed food loses value relative to the immediate food. As discussed later, biologists have another interpretation that does not invoke discounting. Pigeons have been the workhorse for self-control experiments, but rats and primates have been tested using this technique as well.

The “delayed gratification” technique provides a second method to study intertemporal choice in animals (Figure 2(b)). This method mirrors Walter Mischel’s pioneering work on delayed gratification in children. In the animal version, a stream of food rewards accumulates over a period of time. For instance, a grape appears in front of the subject every 5 s. The catch is, once a subject interrupts this stream by reaching for or eating the food, the stream stops. So if subjects can delay their gratification, they will receive all of the rewards in the stream; however, they constantly face the temptation to consume the available rewards. Rather than choosing between two options, in the delayed gratification paradigm, subjects choose when to stop waiting for the reward. Researchers have primarily used this method with primates but occasionally with pigeons as well.

#### Hyperbolic Discounting

Most work on animal intertemporal choice uses the self-control paradigm and assumes that this tests temporal discounting in their subjects. With a series of indifference points, one can derive a discounting function that quantitatively describes how reward values decrease with delays. Recall that exponential discounting (Equation [2]) implies a constant rate of discounting. Unfortunately, experiments in both humans and other animals show little support for this prediction. Instead, the discount rate decreases with time, showing high discounting at short delays and a lower rate at longer delays (Figure 1). This type of discounting is termed “hyperbolic discounting.” Psychologists favor a particular hyperbolic function that describes how the present value of a reward amount  $A$  decreases with the delay  $t$ :

$$V = \frac{A}{1 + kt} \quad [3]$$

where  $k$  represents a discounting parameter that accounts for the steepness of the slope. This model has a declining discounting rate and describes data from pigeons, rats, and humans quite well.

The actual rate of discounting also violates the economic model. If viewed as a proxy for the interest rate in humans or the interruption rate in animals, the rate of discounting should be rather small. A rational investor should have a discount rate that matches available interest rates (around, say, 5% per year). In experiments and "field studies" in humans, the estimated discounting rates often range between 10 and 30% per year for delays beyond 1 year (and are much higher for shorter delays). Humans, therefore, choose much more impulsively than predicted by economic analysis because they have strong preferences for sooner outcomes. Animals also exhibit impulsive preferences, but on an even shorter time scale, typically only waiting for seconds or minutes for delayed payoffs. This would imply implausibly high interruption rates (up to four interruptions per minute!) to discount the future at this level. Thus, from a psychological perspective, high levels of impulsivity remain a puzzle. Rather than offer ultimate explanations of behavior, the psychological perspective emphasizes the cognitive variables underlying behavior.

### **Cognitive Variables**

The psychological study of intertemporal choice often highlights how individuals overcome temptation for short-term gratification. A number of cognitive variables play key roles in trade-offs between short- and long-term rewards.

#### *Commitment*

One way to avoid the temptation of immediate gratification is to use external commitment devices that force an individual to choose the delayed option. Examples of commitment devices in humans include automatically transferring salary into a retirement account to save money for the future, throwing away a pack of cigarettes to avoid smoking, placing the alarm clock across the room to avert the draw of the snooze button, and Ulysses lashing himself to the mast of his ship to resist the Sirens' songs. Although little or no evidence suggests that animals actively pursue commitment devices, they can use them when available. For instance, Howard Rachlin and Leonard Green conducted a series of experiments in which pigeons faced an additional choice before experiencing the standard self-control choice between a smaller-sooner and larger-later option. In one version of the task, the subjects could choose between experiencing a delay, then continuing on to the standard self-control choice or experiencing a delay, then automatically receiving the larger-later option. This second choice represents a form of commitment because

the pigeons can commit themselves in advance to the larger-later option. Interestingly, the pigeons did use the commitment device, and most subjects significantly preferred it when a long delay separated to two sets of choices. Therefore, the pigeons used commitment if the temptation was far enough in the future.

#### *Reward magnitude*

Both the exponential and hyperbolic models predict that the absolute magnitude of the rewards should not matter; only the relative magnitudes should matter. So, the choice between one food item now and three items tomorrow should be devalued the same way as 20 items now and 60 items tomorrow. Only the threefold increase in reward amount should matter. The absolute magnitude does, however, influence choices in humans: the discounting rate decreases as the magnitude increases. So, human subjects choose more patiently (meaning that they opt for the larger-later reward more often) when assessing rewards in hundreds or thousands of dollars compared to tens of dollars. Interestingly, this "magnitude effect" does not appear in animals. The ratio of rewards influences choices rather than the absolute magnitude. Testing the magnitude effect, however, proves difficult in animals because the magnitudes cannot scale to the same degree as in humans. Experiments in humans can vary hypothetical monetary payoffs over several orders of magnitude, whereas animal food rewards can only vary over a single order of magnitude. Thus, as we will see in the next section, the currency of the reward is a key aspect of intertemporal choice.

#### *Currency*

Food is the most commonly used reward currency in studies of animal intertemporal choice because it is easy to manipulate, highly motivating, and slow to cause satiation. Most experimental studies show that animals will wait for seconds or minutes for food rewards. Water provides another primary reward (a reward needed for survival) used in studies of intertemporal choice. Self-control studies rewarding deprived rats with water show similar patterns as when using food: rats only wait for a few seconds and their discounting function matches the hyperbolic model. Unfortunately, we do not have good experimental data on other currencies such as mating opportunities or social contact, but this provides an important avenue of future research. If intertemporal choices are adaptive in animals, we might expect that different currencies vary in how they lose value over different time scales, and animal intertemporal choices might match this variation. Food may elicit a strong preference for immediacy because it often does not persist long in the environment—competitors will take it if you do not. Also, food is, of course, something animals constantly need, so discounting of food may result from close ties to metabolic rates.

Currency effects appear more prominently in humans. Food, money, and health options all seem to show hyperbolic discounting but over different time scales. In fact, when tested with food in a similar way as other animals, humans also show very impulsive choices. So, food seems to be a universally impulsive currency. However, money and health options allow for much longer-term delays, even if they are shorter than those predicted by economic models.

#### Attention

Mischel's work on delayed gratification in children highlights the role of attention. In his design, an experimenter placed a single treat (cookie or marshmallow) in front of a child and said that she would leave the room. If the child waited and did not eat the treat until she returned, the child could have two additional treats. The experimenter would then leave the room and measure how long the children would wait (up to 15–20 min). Mischel and colleagues manipulated attention in several ways. First, they simply varied whether the children could see the treat. When the treat was hidden, the children waited significantly longer than when it was visible. Next, the experimenters drew the children's attention to the treat in different ways. They either focused the children's attention on the delicious properties of the treat (e.g., "the marshmallow sure looks like a yummy, sweet treat, doesn't it?") or had them divert their attention by thinking of the treat as something else (e.g., "imagine the marshmallow is a soft, fluffy cloud"). Again, diverting attention from the treat as food increased patience. Similar studies in animals have used the delayed gratification paradigm. Pigeons, for instance, can wait longer when their food is not visible, and chimpanzees can wait longer when experimenters provide toys to distract subjects from the accumulating food. The availability of distraction therefore can increase patience—reducing attention to waiting makes delays more tolerable.

#### Mechanisms of control

One of the most interesting and controversial topics in psychology is the nature of mechanisms of control over behavior. Are behaviors consciously or reflexively controlled? Are they genetically determined, learned, or reasoned out? These questions certainly apply to intertemporal choice, but unfortunately we have not begun to address them systematically. Claiming that plants make intertemporal choices suggests that strong genetic mechanisms with relevant environmental input can generate intertemporal choices. Of course, the same can be said of animals. Parasitoid wasps, for instance, can detect cues associated with a short life expectancy (such as lower barometric pressure indicating an impending storm). When detecting these cues, they lay more eggs in lower quality hosts than in the absence of the cues. They

therefore accept a lower reproductive output when responding to a shortened temporal horizon. Caching also likely falls under the category of intertemporal choices with strong genetic components. Caching species probably do not weigh the current and future benefits of the seeds in front of them—foresight months into the future seems unlikely. Nevertheless, caching species show extreme flexibility in their behavior, and foresight into a much shorter future seems perfectly reasonable. Experiments with scrub jays show that they attend to the decay of food, the time since caching, the presence of possible cache thieves, and future need. Thus, they have an extraordinarily flexible system for dealing with delayed rewards, although we do not fully understand how they represent the future. The abstract representation of time in humans allows us extreme flexibility in anticipating future payoffs—we can mentally travel in time. Although other animals can plan for the short term (hours, maybe days), the full scope of their mental time horizons remains unclear.

### Evolution of Intertemporal Choice

The psychological approach offers insight into the mechanisms of intertemporal choice, but it does not offer a satisfying explanation of the circumstances under which animals should choose patiently or impulsively. An evolutionary account, however, can make specific predictions about temporal preferences and the change in discount rate over time. The evolutionary view stresses the fit between the decision mechanisms used to make temporal trade-offs and the environment in which these mechanisms evolved. Thus, natural selection favors a good fit between the decisions and the ecology of organisms—temporal preferences should be "ecologically rational" rather than economically rational. This perspective leads to predictions that can account for some of the variation in species differences in patience and impulsivity.

The ecological rationality perspective suggests that decision mechanisms should fit the environment in which they operate. Thus, intertemporal choices should match the kinds of problems often faced by animals. This may explain animal impulsivity in the self-control paradigm. Rather than discounting, the rats and pigeons in these experiments may use simple rate-maximizing rules that are adapted to foraging in patches (maximizing intake also results in a hyperbolic discounting function). David Stephens and his colleagues have proposed that actual foraging situations rarely have the property of simultaneous choice used in the self-control paradigms (Figure 2(a)). Instead, animals typically choose when to leave a patch. A rule that maximizes the short-term intake rate:

$$\frac{A}{t+h} \quad [4]$$

where  $t$  represents the delay and  $h$  represents the time required to process the food, makes similar predictions as the long-term rule (Equation [1]) in the patch situation. In the self-control situation, however, it predicts impulsive choice. Experiments with blue jays suggest that they make appropriate decisions in a patch situation, but choose more impulsively than expected in a self-control situation. This short-term rule is ecologically rational because it works well in a more naturalistic environment in which animals forage in patches.

Ecological rationality can also make predictions about species differences in intertemporal choice because species differ in their ecologies. Although relatively few animals have been tested systematically, interesting patterns emerge in the data across species. Comparing species can pose difficulties, especially with phylogenetically distant species. With more closely related species, however, the comparative method can yield interesting insights. For instance, chimpanzees and bonobos are sister taxa that share many morphological, ecological, and behavioral similarities. Yet, they differ in key aspects of their foraging ecologies. Although their diets overlap substantially, chimpanzees often hunt for food, whereas bonobos spend more time consuming the abundant terrestrial herbaceous vegetation in their habitat. This means that chimpanzees frequently face delays in food consumption: they decide to hunt and then must wait until capturing food before consuming it. Bonobos, in contrast, rarely hunt, instead feeding on the plentiful vegetation that is virtually immediately accessible. Ecological rationality would predict that these differences in foraging ecology should translate into different decision mechanisms and preferences between the two species. In fact, chimpanzees are more patient in the self-control task than bonobos, reflecting the differences in natural foraging. Although chimpanzees and bonobos differ, they wait longer than any other species systematically tested so far. Macaques wait for an intermediate length of time, and capuchin monkeys, tamarins, and marmosets wait as long as pigeons and rats. Yet differences still exist between these species, some of which may result from foraging ecology. The comparative study of intertemporal choice remains in its infancy, and testing more species can help reveal the underlying nature of temporal preferences.

**See also:** Animal Arithmetic; Caching; Mental Time Travel: Can Animals Recall the Past and Plan for the Future?; Optimal Foraging Theory: Introduction; Patch Exploitation; Rational Choice Behavior: Definitions and Evidence.

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