# Surprise! Pigeons and humans respond similarly to unexpected reinforcers [1,2]

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**Abstract**

When a reinforcer for one behavior is usually followed by a reinforcer for a different behavior, organisms choose the response likely to produce the next reinforcer. This pattern of behavior may suggest prospective control resulting from learned relations between reinforcers, or it may reflect strengthening of switching, rather than of a single response. We sought to assess further the degree to which operant behavior can be explained in terms of prospective processes. We asked whether reinforcers could guide pigeons' and children's behavior as a result of prospective processes, both when those reinforcers strictly alternated between responses in a predictable sequence, and when they occurred at a surprising point in that sequence. Pigeons and children learned to choose the response that did not provide the most recent reinforcer, and tended to treat surprising reinforcers in just the same way as predictable ones. The tendency to choose the not-just-reinforced response after surprising reinforcers as well as expected ones is consistent with the idea that reinforcers guide behaviour via their discriminative properties, rather than by strengthening operant classes. Our findings replicate and extend previous work showing reinforcer control depends on what a reinforcer signals about the likely future, rather than on the behavior most recently reinforced in the past.

***Key words***: *Reinforcer, surprise, prospective control, stimulus control*

**Resumen**

Cuando el reforzador de un comportamiento es usualmente seguido por el reforzador de un comportamiento diferente, los organismos eligen la respuesta con la que es más probable obtener el siguiente reforzador. Este patrón de comportamiento puede sugerir un control prospectivo, resultado de las relaciones aprendidas entre reforzadores o bien, reflejar el fortalecimiento de la conducta de

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alternancia, en lugar del fortalecimiento de una única respuesta. En este estudio se evaluó si los reforzadores podrían guiar el comportamiento de palomas y niños como resultado de procesos prospectivos, cuando los reforzadores se alternaban estrictamente entre respuestas en una secuencia predecible y cuando ocurrían en un punto sorpresivo de esa secuencia. Las palomas y los niños aprendieron a elegir la respuesta que no había sido recientemente reforzada y tendieron a responder a los reforzadores sorpresivos y predecibles de la misma manera. Nuestros hallazgos replican y amplían trabajos previos que muestran que el control del reforzador depende de lo que señala sobre el futuro probable, más que del comportamiento que haya reforzado en el pasado reciente.

**Palabras clave:** *Reforzador, sorpresa, control prospectivo, control de estímulos*

The events that follow a behavior determine whether that behavior is repeated subsequently. Not all events are equal in terms of their power to change behavior; many effects depend on the context in which an event takes place. Surprising events – events whose occurrence at a time, location, or after a particular response is not predictable on the basis of past experience – often cause larger changes in behavior than events that might be expected on the basis of recent experience. For example, in respondent conditioning, behavior changes more rapidly when events are less predictable on the basis of experience (Rescorla & Wagner, 1972). When one element of a compound stimulus has previous been paired with an event, the other element will typically fail to elicit a response after the compound stimulus has been paired with the same event (*blocking;* Kamin, 1968). If the compound stimulus is paired with a novel – and hence surprising – event, then blocking does not occur (e.g., see Stickney & Donahoe, 1983; Dickinson et al., 1976; see also Arcediano et al., 1997; Freeman et al., 2013; Holland,1984; Jones et al., 1992; Solomon, 1977; Stock et al., 2017). Similarly, in operant conditioning, reinforcers for a response that seldom produces a consequence tend to occasion much larger shifts in behaviour than reinforcers for an often-reinforced response (e.g., Davison & Baum, 2000; Landon & Davison, 2002). Events that are surprising are also more likely to be remembered, both in respondent (e.g., Terry & Wagner, 1975) and operant (Maki, 1979) conditioning. There is also electrophysiological evidence for the importance of surprise; the unexpectedness of a reinforcer modulates the event-related potential that it produces in an electroencephalogram pattern (McGill et al., 2017). Thus, surprise determines in part the degree to which an environmental event guides behavior.

Events do not have to be surprising in order to guide behaviour. When environmental events occur with temporal and spatial regularity, repeated exposure to the environment means each event is unsurprising, since likely future events may be predicted on the basis of recent past experience. Under these conditions, the relationship between one reinforcer and the next appears to guide behaviour, and reinforcers appear to function as discriminative stimuli signalling likely future outcomes (e.g., see Cowie, 2020; Cowie & Davison, 2016, 2020, Killeen & Jacobs, 2017; Shahan, 2017, for reviews). If the next reinforcer is more likely to occur for the response that did not just produce it, then choice will favor the not-just-reinforced response (e.g., see Cowie et al., 2011; Krägeloh et al., 2005). These discriminative effects of reinforcers appear subject to degradation by perceptual errors (Cowie et al., 2016; Cowie & Davison, 2020a,b). Thus, while surprise may facilitate learning because of its effects on attention and memory, experience permits the development of expectation, and behaviour that is appropriate in the context of likely future events.

These expectation-based reinforcer effects may also be explained as the result of strengthening (Skinner, 1938) of a broader operant class (e.g., see Cowie, 2020; Cowie & Davison, 2016; Simon et al., 2020, for discussion). That is, when reinforcers strictly alternate between response locations, the reinforcer might strengthen the entire pattern of behaviour necessary to occasion a reinforcer (i.e., an extended pattern of alternation), rather than the single response occurring before the reinforcer. We sought to assess whether apparent control by the likely next reinforcer is in fact strengthening of an extended pattern of behavior, using surprising reinforcers in a highly predictable environment. We also sought to extend the finding of solely discriminative control by reinforcers to a novel population – humans. Pigeons and children responded on a two-alternative choice task in which reinforcers strictly alternated between response locations. Once behaviour was under asymptotic control by the contingency, we occasionally inserted a "surprising" reinforcer in the sequence of strict alternation. The reinforcer was surprising in that it was produced by the response that would *not* be expected to produce it given the pattern of alternation between reinforcer locations. If, during training, an extended pattern of strict alternation had been reinforced, then these surprising reinforcers should be followed by a tendency to resume the interrupted pattern and repeat the just-reinforced response. If, on the other hand, training had caused the reinforcers to become discriminative stimuli, then each surprising reinforcer should be followed by choice for the response that did not produce that reinforcer. Since surprise appears to magnify the effects of an event on behaviour, these surprising reinforcers should occasion relatively extreme choice. In this way, we used surprising reinforcers to assess how past experience exerts control over responding.

## Method

### *Subjects*

**Pigeons:** Five pigeons numbered 101 to 105 were maintained at 85% ±15g of their free-feeding body weight. Water and grit were available at all times. The pigeons had previous experimental experience pecking keys for food reinforcers on concurrent variable-interval schedules (see Taylor et al., 2019, for specifics).

**Children:** Four typically developing children aged four years were recruited from local day-care centres in New Zealand. Z, M, and J were fluent in English, and D was fluent in English and Mandarin.

### *Apparatus*

**Pigeons:** Six experimental chambers, each measuring 380 mm high, 380 mm deep and 380 mm wide, were used. The back, left, and right walls were made from sheet metal, with the floor, front wall, and ceiling made from steel bars. The experimental chambers were also the pigeons' home cages. On the right-hand side wall were three keys, each 20 mm in diameter, set 120 mm apart and 300 mm above the floor. Only the two side keys were used. A peck was registered as a response only if it exceeded 0.1 N. On the same wall, a magazine aperture 50 mm wide, 50 mm high and 50 mm deep was situated 160 mm above the floor, centered in the panel. A hopper filled with wheat was raised, and the aperture illuminated, for 3 s during reinforcer delivery. A computer in the neighboring room running MED PC IV controlled and recorded all the experimental events. There was no houselight in the experimental chamber; the room itself was lit instead.

**Children:** Sessions took place in a room at the participant's home (for Z, J, and D), or day-care centre (M), depending on what was most convenient for the parents and the day-care centre manager. At the beginning of each session, the participant was asked if he/she wished to play the game before he/she was brought into a room to participate. The game involved choosing between two opaque tea cups, turned upside down, which were placed on a table in the room. All sessions were video-recorded using a video camera placed half a metre in front of the child.

*Procedure*

Both pigeons and children were exposed to a procedure where two responses were available in each trial, and the response that would produce a reinforcer strictly alternated across trials so that the reinforcer in each trial was always perfectly predictable based on which response had been reinforced in the preceding trial. Reinforcers were available on a fixed-ratio 1 schedule, and each trial terminated once the reinforcer was obtained. Once choice for the just-reinforced response ceased to change systematically, 'surprising' reinforcers that did not conform to the strict-alternation sequence were occasionally delivered.

**Pigeons:** In each trial, the left and right keys were lit yellow, and a single reinforcer could be obtained, and once the reinforcer was obtained the trial terminated. If a reinforcer was arranged on the left key in a trial, the first peck to the left key would produce a reinforcer, and any pecks to the right key would have no consequences. If a reinforcer was arranged on the right key in a trial, the first peck to the right key would produce a reinforcer, and any peck to the left key would produce no consequences. The next trial began immediately after the reinforcer was consumed. The reinforcer in the first trial was allocated to the left key with a probability of 0.5. Thereafter, reinforcers strictly alternated between responses (left and right) across trials. Each session lasted for 41 trials or 60 minutes, whichever occurred first.

Once visual inspection suggested that choice measures of responding were stable for all pigeons (Baseline; 110 sessions), we introduced surprising reinforcers (Testing). When a surprising reinforcer occurred, it was arranged at the same key-location as the reinforcer in the previous trial (i.e., its position in relation to the reinforcer in the last trial was surprising); it replaced an 'expected' reinforcer. Surprising reinforcers would occur no earlier than the sixth trial in a session. In each trial, the probability that a surprising reinforcer would be arranged was .05. More than one surprising reinforcer could be arranged in a single session, but consecutive surprising reinforcers could not occur within five non-surprising trials of each other.

**Children:** *Preference assessment.* Before beginning the experiment, a Reinforcer Assessment for Individuals with Disabilities (RAISD; Fisher, Piazza, Bowman, & Amari, 1996) assessment was used to determine preferred items. At the beginning of each session, preference for these items was assessed using a procedure similar to the free-operant method described by Roane et al. (1998). All reinforcers were freely laid on the table, and the participant was asked to choose ten items for a ten-trial session, and line them up in the order s/he wanted to obtain them from trial 1 to 10 in a particular session. Table 1 shows the reinforcers available to each participant in each session.

During the experiment, participants played a treasure hunt game where they were presented with two up-turned tea cups, each of which could be lifted one at a time to reveal the presence or absence of 'treasure' (the reinforcer). One cup was placed on the participant's left, and the other on their right; the cup concealing the reinforcer was strictly alternated across trials. If the participant chose the cup that did not contain the reinforcer, they were allowed to choose again. Each trial lasted until the participant found the reinforcer. Once the cup concealing the reinforcer was chosen, the trial ended, and the participant was allowed to play with (tangibles) or eat (edibles) the item. The participant was then asked to cover their eyes or turn away while the experimenter positioned the reinforcer for the next trial. After each block of ten trials, the experimenter asked the participant if s/he wanted to take a break.

Once choice for the just-reinforced response in three consecutive sessions did not differ more than 10 percent (Baseline), surprising reinforcers were introduced (Testing). The surprising reinforcer was arranged in the same cup-location as the reinforcer in the previous trial (i.e., its position in relation to the reinforcer in the last trial was surprising); it replaced an 'expected' reinforcer. A surprising reinforcer occurred once between the third and eighth trial in a block of ten trials, in a trial randomly chosen before the block began. The trial in which the surprising reinforcer (henceforth termed a *surprise*) would occur was generated by a random number generator in Excel. Then the numbers were sampled without further replacement. Hence, if a surprise occurred on the seventh trial in one block, a surprise would not occur on the seventh trial in the next block that included a surprise. Each block of trials containing a surprising reinforcer was followed by a block of trials with no surprises, so that a surprising reinforcer occurred only once in every 19 trials. Five surprising reinforcers were delivered in total. Table 1 shows the number of Baseline blocks, and the type of reinforcers used for each participant.

## Results

The following analyses used only the first response in each trial, for both pigeons and children. To assess asymptotic control by the relation between reinforcers, we analysed the proportion of responses made to the alternative that should have contained the reinforcer in that trial, given the pattern of alternation (i.e., proportion of choices to the not-just-reinforced location). We calculated two separate measures of choice following an expected reinforcer. Baseline choice was calculated from stable responding from the last 3 blocks of Baseline for children, and from the last 10 sessions of Baseline for pigeons, using data from all trials in these blocks/sessions except those that did not follow a reinforcer (for the children, we excluded the first trial in each block, and for the pigeons, we excluded the first trial in each session). Choice in Testing was calculated using the first response in trials following an expected reinforcer in sessions during which surprising reinforcers occurred. Our analysis of this *Testing* phase excluded the first trial in each block (children) or session (pigeons), and the trial after each surprising reinforcer. Comparison of Baseline and Testing choice measures allowed us to assess whether the introduction of surprising reinforcers affected behavioural control by the contingency. We also calculated the proportion of responses to the not-just-reinforced location after a surprising reinforcer, using the first response in each trial that followed a surprising reinforcer. These measures are plotted in Figure 1 for children (left panel) and pigeons (right panel).

Table 1. Reinforcer types and numbers of Baseline blocks and surprising reinforcers

| Participant | Reinforcers | Baseline blocks |
|---|---|---|
| Z | popcorn, crackers, stickers | 10 |
| M | green beans, popcorn, chips, raisins, stickers | 10 |
| J | popcorn, yogurt drops, stickers | 4 |
| D | popcorn, raisins, Lego, stickers | 4 |

Table 2. Z scores for individual participants and pigeons in Baseline, Training, and Testing.

| Participant | Baseline | Training | Testing |
|---|---|---|---|
| Z | 2.18 | 1.29 | 0.45 |
| M | 3.57 | 0.71 | 1.34 |
| J | 4.43 | 5.33 | -2.24 |
| D | 3.02 | 1.21 | 0.82 |
| Pigeon 101 | 2.80 | 2.26 | 2.19 |
| Pigeon 102 | 19.70 | 16.25 | 5.24 |
| Pigeon 103 | 3.20 | 1.39 | 1.52 |
| Pigeon 104 | 14.60 | 13.25 | 3.05 |
| Pigeon 105 | 6.60 | 10.10 | 2.65 |

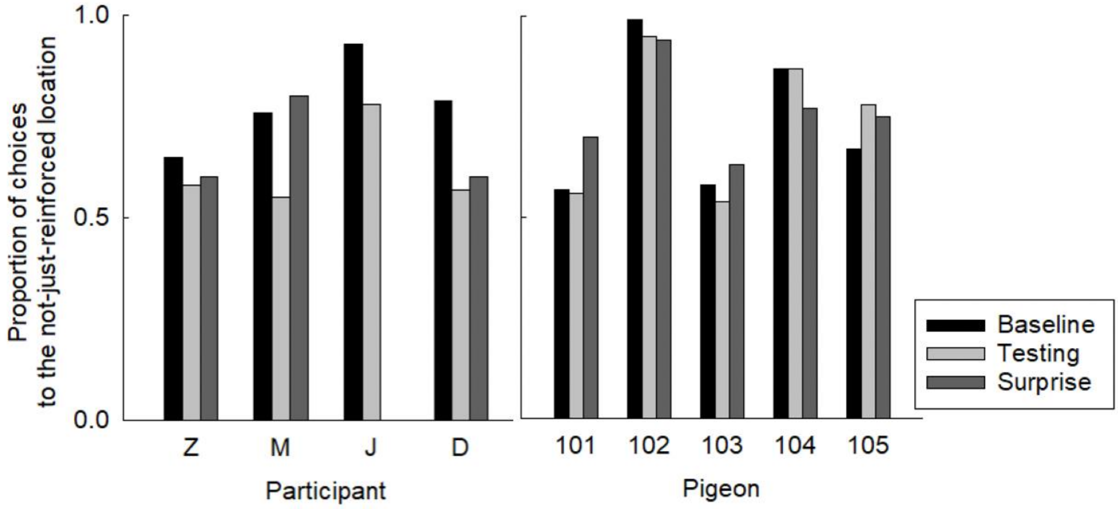


**Figure 1.** Proportion of responses to the location that did not produce a reinforcer in the last trial for children and pigeons. Note: Black bars represent choice following expected reinforcers in Baseline, before any surprising reinforcers were introduced. Light grey bars represent choice following expected reinforcers once surprising reinforcers occurred occasionally. Dark grey bars represent choice following surprising reinforcers.

Figure 1 shows that both children and pigeons tended to choose the response that had not produced the last reinforcer after expected reinforcers in Baseline, and in Testing. This pattern of alternation was significant ($p < .05$) according to a binomial test for all children (Table 2). Choice measures were still greater than .5 in Testing for all participants and pigeons, indicating a tendency to choose the response that had not produced the most recent reinforcer. However, this choice was less extreme than in Baseline for all children and for three of the five pigeons. For the children, only J's pattern of alternation remained significant in Testing (Table 2) – though pooling data across the remaining three participants did show significant alternation. The pattern of alternation remained significant in Testing for all pigeons except Pigeon 103 (Table 2). Thus, pigeons' choice following expected reinforcers was affected to a lesser degree by surprising reinforcers in other trials than was the children's choice.

Figure 1 shows that surprising reinforcers also tended to be followed by choice for the not-just-reinforced location for children (left panel) and pigeons (right panel), with the exception of J who always chose the same cup that had contained the surprising reinforcer. The effect of the introduction of surprising reinforcers on choice following expected ones (Testing) means that the appropriate comparison against surprising reinforcers is choice following expected reinforcers in Testing, rather than Baseline. Surprising reinforcers produced more extreme choice for the not-just-reinforced response relative to expected reinforcers in Testing for all children except J. For the pigeons, alternation was more likely following a surprising reinforcer than an expected one in Testing for Pigeons 101 and 103, and less likely for the three other pigeons. Patterns of alternation following surprising reinforcers were significant for all pigeons except Pigeon 103 (Table 2). Thus, in general, differences between the effect of surprising and expected reinforcers were evident in the extent, but not in the direction, of choice. Both surprising and expected reinforcers shifted choice toward the not-just-reinforced location.

## Discussion

We asked whether reinforcers could guide behavior solely as a result of their discriminative properties, both when those reinforcers strictly alternated between responses in a predictable sequence, and when they occurred at a surprising point in that sequence. Both pigeons and children learned to choose the not-just-reinforced response during baseline. This result replicates and extends previous findings showing control by what a reinforcer signals about likely future events (e.g., Cowie et al., 2011, 2021; Krägeloh et al., 2005). Both pigeons and children tended to treat surprising reinforcers in the same way as they treated Baseline reinforcers, in that choice was toward the not-just-reinforced response, suggesting that reinforcers control behaviour as a result of their discriminative effects, and not because they strengthen an extended pattern of responding.

The location of the next reinforcer was perfectly predictable, and generally pigeons and children chose the next-reinforcer location accordingly. Nevertheless, neither pigeons nor children did so in every single trial (Figure 1). Exclusive choice is unusual, even in environments in which such choice would be entirely appropriate either because of the systematic relation between one reinforcer and another (e.g., Davison & Jones, 1998; Krägeloh et al., 2005), or because of the systematic relation between stimulus conditions and subsequent events (e.g., Cowie et al., 2020). This imperfect control by the relation between one reinforcer and the next may reflect *misallocation* (Cowie et al., 2014; Davison & Jenkins, 1985), where a reinforcer obtained for one response generalizes to the other response, and/or forgetting that occurs after a brief stimulus ends (e.g., Cowie et al., 2011; 2017). Alternatively, non-exclusive choice may reflect an adaptive strategy that facilitates detection of changes in contingency. Exclusive choice for the not-just-reinforced response would mean that if reinforcers did become available for the just-reinforced response, such a change might not be detected (see also Baum & Davison, 2014; Cowie et al., 2016a,b; Racey et al., 2011). Non-exclusive choice may thus be essentially future-oriented, allowing the organism to adapt rapidly should future conditions cease to mirror the past.

Choice after surprising reinforcers may shed some light on the process that caused control by the future to be imperfect. Surprising events are often reported to have larger impacts than unsurprising events on respondent (e.g., Rescorla & Wagner, 1972; Stickney & Donahoe, 1983; Dickinson et al., 1976; Terry & Wagner, 1975) and operant (e.g., Davison & Baum, 2000; Landon & Davison, 2002; Maki, 1979) behavior. In the present study, surprising reinforcers might have been expected to enhance choice for the not-just-reinforced response by marking (e.g., Lieberman et al., 1979) the preceding response, and hence improving memory (Maki, 1979) for it, thus improving memory for the discriminative stimulus signalling the next-reinforcer location in surprising trials relative to unsurprising ones (see also Cowie et al., 2011; 2017). Of course, such an effect would be evident to a greater extent in the behavior of individuals with poorer memory. Thus, if control is impacted by forgetting, surprising reinforcers should have larger effects on choice relative to expected reinforcers for individuals whose choice in Baseline and Testing was closer to 0.5 (indifference). In contrast, if control is imperfect because misallocation distorts the relation between one event and the next, then choice after surprising reinforcers should be similar to choice after expected reinforcers (Baseline and Training), reflecting the *apparent* uncertainty about future events. Our surprising reinforcers produced more extreme choice relative to expected reinforcers (Testing) for all children, and for Pigeons 101 and 103 – pigeons who showed the weakest performance in Baseline and Testing. For the other pigeons, choice for the not-just-reinforced response relatively similar after surprising and expected reinforcers. Thus, imperfect control in Baseline and Testing may have reflected both occasional forgetting of the just-reinforced response, and occasional misallocation, to varying degrees for different individuals.

The memory-enhancing effect of surprising reinforcers for all children and only some pigeons should not be taken to imply the children had worse memory than the pigeons. The pigeons' body orientation after they accessed the magazine at the end of a trial may have provided some enduring reminder of the just-reinforced response (e.g., see Cowie et al., 2020; McMillan & Roberts, 2012; Rayburn-Reeves et al., 2018). The children, on the other hand, sat in the same location and covered their hands with their eyes, and thus body (or hand) position could not provide a reminder stimulus.

Despite differences in the extent of choice following a surprising reinforcer across individuals, the *direction* of choice was the same following surprising and expected reinforcers, across both pigeons and children, with only one exception. Unlike four of the children and all of the pigeons, who treated surprising reinforcers as Baseline reinforcers, J always chose the same cup that had contained the surprising reinforcer. It is difficult to explain J's behaviour as the result of strengthening of an extended pattern of alternation when such a pattern was clearly not strengthened for all other children, and for all pigeons. Perhaps J's treatment of surprising reinforcers reflects control by an extended sequence of events, in the context of which the surprising reinforcer appeared as an anomaly, rather than as a potential indicator of environmental change. Indeed, after one surprising reinforcer, J somewhat gleefully informed the experimenter that the experimenter had made a mistake. Certainly, J was the only child for whom strict alternation remained significant following the introduction of surprising reinforcers, suggesting J's behaviour was slower to adapt to the unavoidable reduction in the strength of the correlation between subsequent reinforcer locations. Although each reinforcer could be predicted on the basis of the previous reinforcer, it could also be predicted on the basis of reinforcers obtained further back in time – that is, on the basis of the extended sequence. In the context of the preceding sequence of reinforcers, a surprising reinforcer provides conflicting information about the likely next-reinforcer location. A long history of the sequence or past reinforcers being a reliable discriminative stimulus for subsequent reinforcers might well push control toward the sequence, and away from the anomalous surprising reinforcer.

Overall, the pattern of results was similar for pigeons and children, underscoring the generality of the discriminative effects of reinforcers. One notable difference was the impact of the introduction of surprising reinforcers on choice following expected reinforcers (*Testing*). Such reinforcers reduced three of our four children's tendency to choose the next-reinforcer location following expected reinforcers, but had no systematic effect on the pigeons' choice. Our pigeons had more extensive exposure to Baseline contingencies than did our children (110 41-trial sessions relative to several 10-trial blocks). Behaviour changes less rapidly as environments change less rapidly (Hunter & Davison, 1985; Davison & Baum, 2000), and hence we might expect behaviour in the more static pigeon-experiment environment to be slower to adjust to apparent changes in the environment. Thus, the attenuated preference in Testing may reflect the children's rapid adjustment to an apparent change in the correlation between one reinforcer and the next, as a result of more limited experience, rather than species-specific differences in learning.

In conclusion, our findings add to a growing body of work demonstrating that simple operant behaviour depends on the likely future, as extrapolated from the past. Like pigeons, human children choose in accordance with what is likely to produce the *next* reinforcer, even when this requires a response other than the one that has most recently been followed by a reinforcer. Control by the likely future was imperfect for both pigeons and humans, underscoring the importance of memory and discrimination in operant learning. Taken together, these findings suggest reinforcer control is fundamentally prospective, arising from learned relations between events, and not from changes in the strength of behavior.

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