

The Logic of Ground Squirrels:

A Window into the Reduction of Decision Theory to Evolutionary Processes?

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BIOEE 2070
Provine
December, 2008

Table of Contents

- I. Preliminary Remarks
- II. Owings' Ground Squirrels and 'Decision under Uncertainty'
 - Part (1): Ground Squirrel Predator-Assessment Behavior
 - Part (2): Decision Theory in Formal Logic
 - a. Figure 1
 - Part (3): Reformulating Sequence₁ as a Decision Tree Diagram
 - a. Table 1
 - b. Figure 2
- III. Theory Reduction and the Threat of Multiple Realizability
 - Part (1): Nagel's Criteria for Theory Reduction
 - Part (2): Cooper's Thesis
 - Part (3): Multiple Realizability
- IV. Summary
- V. Notes
- VI. Bibliography

I. Preliminary Remarks

What is the relationship between evolutionary biology and logical theory? This question immediately demands our attention. We, as ostensibly reasonable agents, should like to know *where* our formal systems of logic come from. Are they ours in virtue of the unique intricacy of the human mind? That is, did we think them up, *a priori*, without looking to experience? Or are they in some way presupposed in biological processes? Did we simply draw these logical principles out from an evolutionarily-informed view of the world around us? These considerations can be subsumed under a more general inquiry: From where do logical principles obtain their validity – our internal cognitive make-up, or the constitution of the external world?¹ To put it simply: Is the world ordered beyond our mind's representation of it, or do we impose order on the world? These umbrella questions will form the backdrop of what is to follow. Before approaching them, however, let us take a step back.

What allows for us to ask about the relationship between evolutionary biology and logical theory? What are the conditions necessary for an inquiry into the perceived connection between such seemingly disparate realms of thought? The answer rests on a whole lineage of research concerning nonhuman animal cognition which points towards the presence of logical reasoning in forms of life lower on the evolutionary 'chain' than *Homo sapiens*.² It is precisely these empirical data that open up the theoretical landscape within which questions of the relation between evolution and logic may be posed. For if logical reasoning is a phenomenon subject to differences of *degree* in biologically distinct species, then it seems at least possible that this phenomenon could be determined in accordance with evolutionary processes. Thus, an inquiry into the presence of logical

cognition in nonhuman animals and the biological evolution of the mental capacities necessary for such cognition will lead us inevitably toward those fundamental questions outlined in the previous paragraph.

With these considerations in mind, we may divide the following writings into two intimately related, but nevertheless distinct sections. The first section will address a largely empirical question: Do nonhuman animals display ‘logical’ behavior? My answer will be in the affirmative. My argument will draw on the empirical data gathered by Donald H. Owings on California ground squirrels (Owings 2002). I will attempt to map this behavioral data onto the model of human decision theory offered in standard logic. This ‘mapping’ of the squirrels behavior will be used to suggest a preliminary *correlation* between evolutionary processes (the squirrels’ ability to assess predators) and decision theory.

The second section will draw out the consequences of the first. We will ask the following questions: Does this *correlation* between formal decision theory and animal decision-making – evidenced by Owings’ squirrels – entail a *reduction* of the former to the latter?³ Precisely what does it mean for a theory to be *reduced* to another theory? I will argue that, despite our findings in first section, we cannot reduce decision theory to evolutionary theory. Let us begin, then, with the first section.

II. Owings’ Ground Squirrels and ‘Decision under Uncertainty’

In 2002, Donald H. Owings published a study on how California ground squirrels [*Spermophilus beecheyi*] assess and react to their predators. His findings present a detailed account of objective, publicly-accessible nonhuman animal behavior which appears to

suggest certain subjective, privately-accessible cognitive faculties present in squirrels. Let us examine the publicly-accessible information first, before attempting to deduce the subjective conditions *necessary for the possibility* of such data in the first place.⁴

Section II, Part (1): *Ground Squirrel Predator-Assessment Behavior*

California ground squirrels face both aerial and ground predators. Their ground predators – primarily Pacific gopher snakes and Pacific rattlesnakes – pose a frequent and formidable threat. Owings describes a situation in which a maternal squirrel tries to assess a predator snake while simultaneously protecting herself and her five young. Squirrel 09 begins by circling the area surrounding a burrow – the supposed residence of the predator. After failing to locate the predator, she leaves her young to search a nearby burrow, periodically turning back to make sure the snake is not near her young. Finally, she locates the snake and approaches it, coming within a close distance while keeping her young behind her. The squirrels – mother and young alike – confront the snake, approaching and then retreating, until they finally go back into their burrow. By the end of the confrontation, all squirrels are left unscathed except for one pup whose left paw is injured. Squirrel 09 leaves the den, going back out into the open to try to locate the predator. She cannot find him.

We can construct a skeletal sequence (sequence₁) of squirrel 09's behavior at specific times, t_n , from Owings' observations of the events described above.

- (t_1) 09 explores burrow₁
- (t_2) 09 leaves burrow₁ and young
- (t_3) 09 arrives at burrow₂
- (t_4) 09 locates predator
- (t_5) 09 approaches predator

- (t₆) O9 retreats with young
- (t₇) O9 explores burrow₂ again
- (t₈) O9 cannot locate predator

What this simplistic sequence of behavior suggests, for Owings, is that O9 must constantly balance the need for information about the predator with her own survival and that of her young. Of course, the best way for O9 to survive and defend her young depends on information which can only be obtained by being close enough to the predator so as to receive vital identifying clues: “activities that facilitate assessment require getting close to and maintaining sensory contact with the predator” (Owings 22). But this proximity also endangers her life. In sequence₁, O9 retreats from the predator at t₆. This action may have saved the lives of four of her five pups, and possibly herself. But as we see at t₈, her retreat resulted in a lack of further information about the nature and location of the predator. Was the safety of the retreat *worth* the loss of information?

Sequence₁ is just one of many possible ways that ground squirrels might deal with the predators they face. Had O9 continued to approach the predator at t₅, she may have been able to obtain crucial information that would inform future decisions. If O9 could get close enough to size up the snake, she could determine how great the threat is, since large rattlesnakes contain more venomous bites. O9 might also obtain sensory data, if in sufficient range, pertaining to the snake’s body heat. Because snakes are ectothermic, their body heat varies highly according to their level of agitation. If O9 came close enough to intuit the snake’s external temperature, she may know right away that retreat is the best option. All these examples of variable decision-making on the part of ground squirrels are not just hypothetical. According to Owings, the squirrels “differentiate large from small rattlesnakes in ways that are similar to their discrimination of snake species;

they stay farther back from larger rattlers, but monitor them and signal more persistently” (Owings 21). This manifold of variables, probabilities, and trade-offs suggests that a complex network of decision-making must be carried out by these squirrels on a daily basis. The situations get even more detailed when we throw aerial predators into the mix. Squirrel behavior when faced with aerial threats must differ considerably, due to the variable capabilities of such distinct predators. Perhaps choosing to go underground is a good option for escaping a hawk, whereas this would not be so advantageous when confronted with a snake.

So far, we have outlined the research conducted by Owings, and restructured one possible threat-assessment event into a temporal sequence. We have said nothing about the cognitive capacities which may underwrite the squirrel’s behavior. It has been assumed, for the sake of argument, that every ‘decision’ the squirrel makes is really just a ‘mechanistic’ response to certain stimuli, in accordance with a strict behaviorist outlook.⁵ But could our strictly behavioral, temporal sequence be reformulated into something more logical? Before we examine this question, we must first identify precisely what we would be aligning the squirrel’s behavior with. In other words, we need a formal account of what logicians have identified as logical decision-making *in general*. This formalization of decision-making processes – the logical ‘algorithm’ for maximizing utility and arriving at the best possible outcome – is found in decision theory.

Section II, Part (2): *Decision Theory in Formal Logic*

Decision theory aims to provide a systematic account of how a rational agent in a state of uncertainty is to make the best possible decision. Logicians have posited various

equations to best maximize utility. Here, we will be concerned with the most basic and foundational account of decision theory. Let us begin with an example.

A gambler is presented with a choice: he can play either blackjack or roulette. He wants to pick the game that will bring him the most profit, on average. Unfortunately, it is not immediately obvious which game he should choose. In making his decision, the gambler begins by estimating the chances of winning for both games. He concludes that it is *probably* easier to win in blackjack (about a 40% chance of success) than in roulette (about a 35% chance). However, given the amount he wishes to bet, a win in roulette would result in more profit (+\$45) than a win in blackjack (+\$30). Which game should the gambler play?

Decision theory wants to say that there is a logically correct answer to the gambler's dilemma, according to the values and probabilities he has estimated. In order to make the correct choice, the gambler must calculate the expected utility of each game, and pick the game with the highest expected utility. The term "utility" in decision logic refers to anything which is need of maximization. In the gambler example, utility refers to profit. In decision theory, we can measure utility on a linear scale with higher values representing more usefulness. The equation which will maximize the gambler's expected profit (i.e. utility) is called the "rational expectations principle," and it can be summarized as such:⁶

$$\text{Utility} = \Sigma (\text{probability}_1 \times \text{value}_1)$$

This principle says that the expected value of some outcome (e.g. +\$30 for winning) must be weighed by the probability of that outcome actually happening (e.g. a 40% chance of winning). So, on our gambler example, the *utility* of choosing blackjack and winning

comes out to +12 (30 multiplied by .4). But we must also factor in the utility of playing blackjack and losing. Let us say that the gambler initially puts down five dollars to gamble with. Therefore, the *value* of choosing blackjack and losing is -\$5, since the gambler loses what he put down. The *utility* of losing, then, is -3 (-5 multiplied by .6).

In order to calculate the *total* expected utility of playing blackjack on the whole, we need only find the sum of winning and losing. This comes to +7 (12 plus -5). We can represent this final step with the following equation for *total* expected utility, derived from the “rational expectations principle.”

$$\text{Total Utility} = \Sigma [(probability_1 \times value_1) + (probability_2 \times value_2)]$$

Here, each set of probabilities and values corresponds to one of two possible outcomes. On our example, the first set would be ‘winning blackjack’ and the second would be ‘losing blackjack.’ Their sum gives us the total utility of playing blackjack. This number (+7) is arbitrary without something to compare it to. That is why we must next calculate the total utility of playing roulette. After doing the same calculations on the probabilities and values estimated by the gambler, we would find the total utility of playing roulette to be +12.5. Since this number is higher than +7 (blackjack’s total utility), the best choice for the gambler is to play roulette.

The numbers and variables in this example make things seem more complicated than they are. The basic idea of decision theory is simple: the best choice is the choice that maximizes utility. We discover which choice maximizes utility through a systematic consideration of the probabilities of certain outcomes and the “values” (dollar-values, in

our example) corresponding to those outcomes. We can illustrate this process visually in a decision tree diagram [see Figure 1].

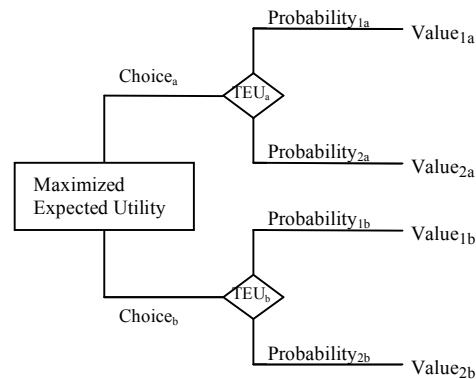


Figure 1: An archetypal decision tree diagram

In Figure 1, the number in the diamond-shaped nodes represents the total expected utility (TEU) for each choice. As stated above, the TEU is arrived at by multiplying the probability of one branch with the value written at the end of that branch (i.e. $\text{probability}_{1a} \times \text{value}_{1a}$), and then adding the two branches. The highest TEU – the maximized expected utility – is written in the square node, representing the utility of the best choice. This tree can be expanded indefinitely, simply by adding branches. To use our gambler example, perhaps a third game is introduced. We would then add in choice_c, along with its projected values and probabilities, and compare its total expected utility to those of the other two choices when evaluating which is highest.⁷ This expanded decision tree diagram may require *more* calculation, but it requires no *new* kinds of calculation; the basic paradigm illustrated in Figure 1 is the same.

What we should take from this overview of basic decision theory is that there is a *universal* formula for making the best possible decision. This strictly formal account of decision-making can be applied to *any* situation in which the following criteria are met:

(1) there is an individual faced with two or more possible choices, (2) the individual wants to make the best choice (i.e. maximize his/her utility), and (3) the individual has the ability to *estimate* the expected value of certain future outcomes and the probability that they will occur.

Does the behavior of Owings' California ground squirrels fit with this formal model for maximizing expected utility? If it does, then we should be able to reformulate the strictly behaviorist sequence₁ from Part (1) into a decision tree diagram much like those used by logicians for maximizing human outcomes.

Section II, Part (3): *Reformulating Sequence₁ as a Decision Tree Diagram*

Recall from Part (1) that the mother squirrel was put in a tough situation. She had to approach the rattlesnake in order to gain information about it while simultaneously keeping herself and her cubs safely beyond striking distance. The behavior in sequence₁ suggests that squirrel 09 faced a critical decision. Either she approach the snake and gain valuable information as to its size and temperature – qualities which correspond directly to how dangerous it is – or she stay back, keeping herself and her cubs safe at the cost of obtaining valuable information. This situation alone accounts for the first criterion of formal decision-making: an individual faced with two or more choices.

The squirrel's situation meets the other two criteria for formal decision-making as well. The situation demands that squirrel 09 make the best possible choice – i.e. that she gain as much information as possible without being injured or killed [criterion (2)]. The squirrel must also consider how valuable future outcomes will be, and how likely they are to happen [criterion (3)]. For instance, in order for the squirrel to successfully deal with

the rattlesnake, she must assign some sort of value to survival and to gaining additional information. This process of valuation need not be complicated; the squirrel could just put some kind of *priority* on one outcome over another – i.e. surviving over dying, gaining information over not gaining information. Further, 09’s estimation of probabilities need not be exact; she must simply predict one thing to be *more likely* than another – i.e. survival to be more likely than death, when far away from the predator.

So it seems that all three criteria for the type of logical decision-making outlined in Part (2) are present in Owings’ squirrel example. We can, therefore, replace the merely *formal* variables from Figure 1 with *actual* content found in the real-life squirrel example. As was said earlier, utility can be anything in need of maximization. In the gambler example, utility corresponded to money. Here, however, we could identify utility as *evolutionary fitness*, or degree to which an organism is capable of reproducing.⁸ The fitness values we attribute to the squirrel will be imaginary, of course, since we can only hypothesize as to her actual values.⁹

Fitness Values for Approaching: Death/Injury = -10 Information = +10	Fitness Values for Staying Back: Death/Injury = -8 Information = +8
Probabilities for Approaching: Caught = .7 Escape = .3	Fitness Values for Staying Back: Caught = .3 Escape = .7

Table 1: Hypothetical Fitness Values and Probabilities for Squirrel 09

What Table 1 shows is that the squirrel’s injuries would be worse (-10) if she is caught after approaching, in virtue of her proximity to the rattlesnake, than if she is caught staying back (-8). However, if the squirrel approaches and manages to escape, she will

gain more information (+10) than if she had stayed back (+8). Of course, the squirrel is more likely to be caught if she approaches (a 70% chance) and less likely if she stays back (a 30% chance). Just as with the example of the gambler, we can illustrate squirrel 09's situation with a decision tree diagram:

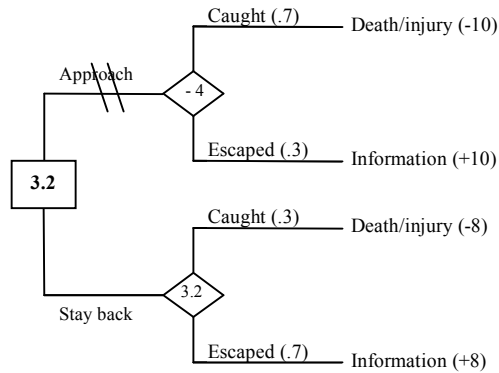


Figure 2: A possible decision tree diagram for squirrel 09

Using the “rational expectations principle,” we can calculate the best decision for squirrel 09 to make. The total expected utility of approaching, given the squirrel's ‘estimated’ probabilities and values, comes out to -4. The total expected utility of staying back comes out to 3.2. Because the total expected utility of staying back is higher, squirrel 09 should choose to stay back instead of approaching the predator. The completed decision tree diagram in Figure 2 indicates the correct choice by crossing out the branch corresponding to the illogical choice.¹⁰

Section II, Part (4): *The Evolution of ‘Wanting and Knowing’*

Owings’ squirrels need not go through the algorithmic or diagrammatical processes outlined in Figures 2 and 3. Not even humans literally draw out decision tree

diagrams in their minds when making decisions. That does not discount the fact that such logical processes may still be carried out by the individual, albeit perhaps only approximately and less systematically. All that matters is that the squirrels *behave as if* they have considered the hypothetical variables in Table 1 and Figure 2. Indeed, the squirrels consistently display behavior which maximizes expected utility. For instance, Owings observes that, on average, the squirrels choose to stay “farther back from larger snakes and [monitor] them more consistently” (Owings 22). Why do they decide to do this rather than to continue to approach larger snakes?

It seems that the squirrels must have some sort of *cognition* regarding the danger that larger snakes pose, or else they would simply continue to approach, in order to gain more information.¹¹ The squirrels’ behavior suggests a crucial interplay between “wanting and knowing” – wanting information, knowing that the snakes pose a threat (Mason 1979).¹² It is precisely this vacillation between “wanting and knowing” that defines formal decision theory, as we have seen in Part (3). A rational agent in a state of uncertainty *wants* to maximize the best possible outcome, given his or her *knowledge* of certain probabilities and values. In logic, this psychological tension between wanting and knowing is mathematically represented by the weighing of some value by a probability. But such tension is also critical to natural selection. According to biologist W.A. Mason, the dynamic of “wanting and knowing” is omnipresent in evolutionary processes.

From a biological perspective the two great themes in the evolution of behavior are ‘wanting’ and ‘knowing’ ... And surely it will be apparent that these themes are interwoven throughout evolution. (Mason 225)

Here, the nexus between formal decision theory and evolutionary biology becomes explicit. The squirrels' ability to reconcile their wants with their knowledge – that is, their decision-making ability – plays directly into their ability to survive. According to fossil records, rattlesnakes have been “a potential source of natural selection” in ancestors of California ground squirrels for 10 million years (Coss 1991). This suggests that the squirrels' ability to assess rattlesnakes has had ample time to evolve. Squirrels who best calculate projected outcomes and make logical decisions are most likely to pass on their genes. The question then arises: Should *logical* decision-making – i.e. the formal logic of the “rational expectations principle” – be considered a trait, inherent in the way life on earth is, and dependent on those evolutionary processes which dictate the biological sphere? The next section will attempt to evaluate this question: first, by defining its scope, and second, by considering the viability of one possible answer to it.

III. Theory Reduction and the Problem of Multiple Realizability

When we considered formal decision theory in Section II, Part (2), we presented a method for maximizing utility which logicians have ‘conjured up,’ ostensibly so that we can model our behavior *after it*. We presented the “rational expectations principle” as an algorithm derived from the human mind, intended to hold universally and necessarily for any ‘contingent’ empirical instance of rational decision-making. In section II, Part (3), we found that the behavior of Owings' California ground squirrels fell quite nicely under this purely logical model: its situational variables accurately correlated with variables in the algorithms of decision theory.

Our investigations thus far, however, reveal a critical ambiguity in the way we have been thinking about the relationship between Owings' squirrel behavior and decision theory: Does squirrel behavior 'fall under' our preconceived model of decision theory, or does the model 'fall under' squirrel behavior? In other words, is decision theory *reducible* to evolutionary theory, or vice versa? Which is contingent and which is necessary? Before answering these questions, however, we must first nail down precisely what we mean by the terms 'fall under' and 'reducible to.'

Section III, Part (1): *Nagel's Criteria for Theory Reduction*

I will begin by presenting one attempt to establish "a workable general conception" of theory reduction (Kim 2006). This attempt is offered by Ernest Nagel (1961). On the Nagelian model, one theory reduces to another if its concepts can be deduced from those of the other theory. We are able to deduce these concepts through certain "bridge laws" that connect the concepts of one theory to another (E. Nagel 1961). We can formulate Nagel's definition of theory reduction as such:¹³

- (Δ) A theory T_2 is reducible to another theory T_1 *if and only if*:
- (i) There are "bridge laws" connecting the concepts of T_2 and T_1 , and
 - (ii) Using these "bridge laws," the concepts of T_2 can be derived from the concepts of T_1

The first criterion for reducibility (i) says that there are laws *connecting* the two theories. These "bridge laws" are just statements that say something in one theory necessarily entails something in the other theory. The necessitation, however, *goes both ways*. An example would be: 'the temperature is hot if and only if molecules are moving quickly.' So for all instances of 'high temperature,' there should be corresponding instances of

‘quick molecular movement.’ Likewise, for all instances of ‘quick molecular movement,’ there should also be corresponding instances of ‘high temperature.’ Laws like this can be referred to as biconditionals – that is, statements in which a concept in one theory necessitates a concept in the other theory, and vice versa [represented in logic as $(p \rightarrow q) \wedge (q \rightarrow p)$].¹⁴ The upshot of having bridge laws between theories is that we no longer have to talk in two separate vocabularies: to use our example, all talk of things being hot or cold can be replaced with talk about the motion of molecules, *without losing any information*.

Nagel’s second criterion (ii) says that these bridge laws must enable us to *derive* all the concepts of one theory from the other, without having to introduce any new terms. So, going with our example of temperature and molecular motion, we could say that, if temperature reduces to molecular motion, we need not look beyond molecular motion in order to *explain* everything about temperature.¹⁵ Within a careful analysis of the concepts of molecular motion, we find everything about temperature.

This is Nagel’s definition of theory reduction. Does the *correlation* between decision theory and evolutionary theory which we established in Section II with Owings’s squirrels meet Nagel’s criteria for *reduction*? William Cooper – who, in his 2001 book, The Evolution of Reason, argues for the full reduction of logic to evolutionary biology – would say yes.

Section III, Part (2): *Cooper’s Thesis*

Cooper’s “Reducibility Thesis” says that “all” of logic “is reducible to evolutionary theory” (Cooper 6, 2). Accordingly, Cooper includes decision theory in his reduction. He argues that its “laws are not just products of historic evolutionary

processes, but are themselves formulable as part of the theory of those processes” (Cooper 12). Here, we see how Cooper’s reduction intends to fill criterion (ii) of Nagel’s formula for theory reduction: he wants to show that we *can* deduce the laws of decision theory from evolutionary processes alone. Cooper’s method is quite like ours was in Section II, although it lacks the real, empirical data that we found in Owings’s squirrels. Cooper maps out hypothetical animal behavior onto decision theory models, claiming that this mapping is commensurate to a deduction of the concepts of decision theory from evolutionary behavior alone.

Of course, Cooper’s “derivation” of decision theory from animal behavior – and our mapping of squirrel behavior – meets only one of Nagel’s two criteria for reducibility. Cooper presupposes that his derivation entails the existence of “bridge laws” connecting evolutionary theory and decision theory. But do these “bridge laws” exist? If they do not, then it seems any effort to deduce one theory from the other will be in vein. Recall from Part (1) that bridge laws enable us to align the terminology of two theories, so that when we talk about a concept in one theory, we know what it corresponds to in the other theory (despite the different terms). Without bridge laws, we would not be able to confirm any *connection* between talk of decision theory and talk of evolutionary processes. In this case, Cooper’s mapping of animal decision-making – and our mapping of squirrel behavior – would represent merely a *correlation* between evolutionary processes and decision theory – not a Nagelian reduction. I will argue that we can confirm no such “bridge laws” between evolutionary processes and decision theory.

Section III, Part (3): *Multiple Realizability*

Observe the following reductive argument, fashioned after Cooper's "Reducibility Thesis":

- (1) An individual, S, makes an evolutionarily-fit decision at time t .
- (2) An individual behaves in accordance with logical decision theory at t if and only if that individual is making an evolutionarily-fit decision at t .
- (3) Therefore, S behaves in accordance with logical decision theory at t .

This argument conforms to the Nagelian formula for theory reduction. There is a "bridge law" connecting the concept of one theory with that of another [premise (2)]. By means of this bridge law, we are able to carry out a deductive argument – a *derivation* of one concept ('behaving in accordance with logical decision theory') from an overarching concept ('making an evolutionarily-fit decision'). So the form of the reduction is right, but is its content true?

Premise (2) is a bridge law because it connects the concept of logical decision-making behavior with the concept of evolutionarily-fit behavior. Recall from our explanation of Nagel's definition (Δ) that bridge laws are biconditionals. So, for any one type of 'logical decision-making behavior,' there should be a corresponding type of 'evolutionarily-fit behavior.' Likewise, for any type of 'evolutionarily-fit behavior,' there should be a corresponding type of 'logical decision-making behavior.' But it is not clear that there is a one-to-one relationship between types of logical behavior and types of evolutionarily-fit behavior. In other words, it seems that one *type* of logical behavior could result in different individual instances, or *tokens*, of evolutionarily-fit behavior, depending on the organism participating in the behavior. That is, one type of logical behavior could be 'multiply realized' by different subjects. Let us clarify this idea of 'multiple realizability.'

A concept is ‘multiply realized’ if it occurs in different ways in different things. For example, the concept ‘being a chair’ could be realized by a flat stone, or a stack of books – let alone an actual wooden chair. In all three of these instances, different particular physical entities function in all the same way – namely, as chairs. Thus, we *cannot* reduce the concept of ‘being a chair’ *just* to ‘being a stack of books,’ nor can we reduce it *just* to ‘being a flat stone.’ A reduction relationship between concepts does not hold when one concept is multiply realizable, simply because that concept cannot be conflated with any *one* thing in particular.¹⁶ So the critical question for us arises: Is the concept of ‘behaving according to decision theory’ multiply realizable?

It seems that the same concept in logical decision theory could be *realized* differently by different species. That is, decision-making behavior could produce some particular instance of evolutionarily-fit behavior, EFB₁, in squirrels, as well as a very *different* behavior, EFB₂, in humans. Humans might employ the same logic of maximizing utility (in accordance with decision theory’s “rational expectations principle”), but behave in a different evolutionarily-fit way. This is because modes of reproduction – the ways in which fitness is maximized – are not always the same across different species (i.e. across different physical realizers). An action that has the logical utility of, say, +8 for both humans and squirrels may result in radically different behavior. It may be logical for a human to stay confined within a cubicle for eight hours a day (+8 on the utility scale) since that human will make money to survive and reproduce. Likewise, it may be equally logical for a squirrel to climb up and down a tree for eight hours a day (+8 on the utility scale). These are two very different evolutionarily-fit instantiations of decision theory.¹⁷

In response to multiple realizability, perhaps we could say: Sure, types of decision-theoretic behavior are multiply realized by different organisms, resulting in different instances of evolutionarily-fit behavior. But there is still a type-to-type reduction, it is just of the form, ‘decision-theoretic behavior reduces to either EFB₁ or EFB₂...EFB_n.’” Under this amended reduction, the *multitude* of possible evolutionarily-fit behavior is taken to represent *one* type of behavior. In logic, this would look like a modified biconditional, where one type of concept (p) is represented by a disjunction of heterogeneous types (q₁ or q₂...or q_n):

$$\text{Disjunctive Bridge Law} = [p \rightarrow (q_1 \vee q_n)] \wedge [(q_1 \vee q_n) \rightarrow p]$$

But does this modified law count as a Nagelian bridge law – of the kind necessary for a reduction? No. For the law above could be reworded as: ‘all things that are p are q₁ or q₂... etc., and vice versa.’ This implies not only that all p’s are q₁’s but also that all p’s are q₂’s. But this is not necessarily true. Perhaps, when go out into the world to confirm our law, we find that there are *no* organisms which exhibit some particular evolutionarily-fit behavior (say, q₉) when behaving according to one type of logical decision-making (p).¹⁸

So it seems that the ‘multiple realizability’ of logical concepts like ‘maximizing utility’ in different organisms make it hard to establish the “bridge laws” necessary for a Nagelian reduction of decision theory to evolutionary theory. Without these laws, we cannot conclude that our investigation into the logical behavior of Owings’s ground squirrels entails a reduction.

IV. Summary

In Section II, our ability to map squirrel behavior onto logical decision theory models suggested a strong *correlation*, or interrelatedness, between decision theory and evolutionary processes. The interplay of ‘wanting and knowing’ came up in both formal decision theory and evolution under natural selection. From Owings’s research, we were able to argue for the presence of logical cognition in California ground squirrels. It was shown that *perhaps* our logical algorithms for maximizing utility can be found by simply observing squirrel behavior.

In Section III, we tried to extend our preliminary *correlation* between decision theory and evolutionary processes to a full-scale *theory reduction*, in line with Nagel’s definition of reduction and Cooper’s Reducibility Thesis. Cooper’s thesis appeared to run into some problems. Based on my objections to Cooper in Section III, it seems we cannot conclude that the correlation between decision theory and evolutionary theory entails a reduction.

Nonetheless, there is some merit to Cooper’s thesis, if not a great deal of potential. That much should be evident from our investigations in Section II. Perhaps we are not yet at the point of being able to establish a strict reduction, but that does not exclude the possibility of other types of connections between formal decision theory and evolutionary processes (Nagelian reduction *via* “bridge laws” is not the only type of reduction).¹⁹ Indeed, even without establishing Nagelian reduction, I think we can quite confidently say that our investigations have shown human logic to be much more evolutionarily-oriented than was previously thought. It remains to be seen whether compelling animal behavior like the predator-assessment of California ground squirrels

will continue to rattle the foundation of what we have taken to be pure, *human* reasoning
– and whether such evidence will one day complete a Copernican-like reversal of how we
look at logic and evolutionary biology.

Notes:

¹ Answers to this question have been given throughout the history of philosophy, varying roughly – at least in the modern period – in accordance with the empiricist-rationalist divide. Tracking this question through its various instantiations in philosophical debate would be far too broad a task for this paper. Suffice it to say that, although I will be focused here mainly on scientific writing, basic logic, and some philosophy of science, there is a robust discourse on this issue present amongst a great number of canonical philosophers, especially from the Enlightenment onwards. One of the most important accounts is that of Immanuel Kant. His idea that the principles of logic are part of the formal conditions of our mind – conditions which *we* bring to experience, without which experience would not even be possible – should serve as a definitive vantage-point which the reader is suggested to assume periodically in order to fairly evaluate the arguments in this paper. Kant’s treatment of logical principles in the Transcendental Deduction of the First Critique of Pure Reason, where he most thoroughly argues his position, is recommended – although I will not address this position here for the sake of brevity.

² Some important studies on this topic include the research of Crist (2003) on earthworms, Wilcox and Jackson (1998) on the vibratory courtship signals of salticid spiders, Gould (1986) on the cognitive mapping of honeybees, as well as Donald Griffin’s exhaustive inquiry into animal consciousness in *Animal Minds: Beyond Cognition to Consciousness* (2001). These are just a few samples from the vast literature on animal cognition that has developed in recent years. For the purposes of this paper, I will focus my inquiries on Owings’ research on California squirrels alone (2002). My aim, rather than reiterating the conclusions of this work, is to draw out the consequences of what Owings’s research suggests. His *speculation* will be solidified through a mapping of squirrel behavior onto logical models.

³ I have chosen to hone in on one specific type of logic – decision theory – since an inquiry into the whole of formal logic (deductive, inductive, game-theory, mathematics, etc.) would be far too large a task for this paper. Perhaps, however, this one inquiry into the *possibility* of a biological reduction of decision theory will have implications for other types of logic as well. That much is left to the reader.

⁴ This regressive type of reasoning that we are about to conduct may not have much force against a vehement skeptic of nonhuman cognitive capacities.⁴ But it is the only type of reasoning we may embark on when approaching the subject-matter at hand – namely, the internal, privately-accessible content of, what philosophers of mind call, ‘other minds.’ The fact is that we will never assume the subjective, first-person vantage-point of an animal’s mind; nor can the animal tell us what it is thinking, if it is thinking (assuming that a linguistic description would suffice in explaining subjective processes). This point is best articulated by Thomas Nagel in his 1974 paper “What Is It Like to Be a Bat?” So, in lieu of an “objective phenomenology” upon which to understand the content of what animal minds internally process, we must settle with, what evolutionary biologist William Cooper calls, “*as-if* descriptions” (T. Nagel 1974, p. 219; Cooper 2001).

⁵ This would be the type of behaviorist theory argued perhaps by Gilbert Ryle in “Descartes’ Myth” (*The Concept of Mind*, 1949). A thorough – and I would say justified – rejection of logical behaviorism is offered by Hillary Putnam in “Brains and Behavior” (*Analytical Philosophy*, 1968). Putnam argues that

⁶ The “rational expectations principle” and the gambler example – although considered standard models of decision theory – are adapted from *Rational Choice in an Uncertain World: The Psychology of Judgment and Decision Making* by Reid Hastie and Robyn M. Dawes (Sage: 2001) pg. 33.

⁷ Or, perhaps there are other ‘conditional’ variables which will affect the probabilities of winning or losing, like the number of players at each table. These variables can be added into the decision tree diagram without changing the basic formula – the “rational expectations principle.”

⁸ The evolutionary fitness of an individual or genotype in population biology would be measured by, according to Hartl (1980), the rate of increase of the population. According to Cooper, fitness values can be applied to decision theories “utility” values since, in either case, the desired goal is a maximization leading

to the best possible choice. A byproduct of applying the logical model to evolutionary fitness is that we have a model for maximizing fitness, and seeing which decisions lead to the reproduction of the individual or genotype. This point will be echoed later when we see how the ground squirrels' decision-making processes – and any possible cognitive abilities corresponding to those processes – appear to be subject to natural selection.

⁹ It should be noted that 09's estimation of values and probabilities may look nothing like our *numerical representation* of them. We will never know how she assigns value to various expected outcomes. But this does not detract from our endeavor. The behavioral data gathered by Owings confirms that the squirrel acts, at least, *as if* she makes estimates and assigns values.

¹⁰ Recall from Part (1) that sequence₁ is just one of many possible situations the squirrel might find itself in. Recall also, from Part (2), that decision tree diagrams can be expanded when extra choices are thrown into the equation, or new conditional variables are taken into consideration. Owings' data suggests that his squirrels take into account a snake's body heat and size after approaching it, and that this information informs further decisions such as 'continue approaching,' 'climb a tree,' or 'escape to a burrow.' Thus, based on Owings' data and the logical structure of decision tree diagrams, we could construct a more complex decision tree for California ground squirrel behavior which takes into account existent conditions and their impact on further decisions. Of course, a more nuanced table of values and probabilities is necessary to accommodate the manifold of choices and conditionals subject to decision-making in a "bushy" diagram. For instance, the value of projected outcomes like death or injury varies not just according to the squirrel's distance from the predator, but also according to how hot or cold the predator is. All of these factors, however, can be filtered through the "rational expectations" formula just the same as in the simple tree diagram of Figure 2.

¹¹ The nature of this cognition could be much different than what we usually associate with 'thinking.' One perspective on animal cognition offered by many cognitive ethologists is that of "emergent" cognition. The idea is that an animal cognizes not necessarily internally, by reflecting mentally on conditions outside of it, but by a holistic and direct cognition of all sensual intuitions. According to Mason (1986), cognitive processes should be considered properties embodied in the organism through all its senses. Animals can acquire knowledge not just through brain states, but also through direct confrontation with stimuli. For Owings, this helps us "shed our anthropocentric views of how animals acquire knowledge, and instead to think of cognitive processes as fundamental to all organisms," not just "a handful of privileged evolutionary newcomers" (Owings, 22; Mason, 306).

¹² Mason, W. A. (1979). Wanting and knowing: A biological perspective on maternal deprivation. In E. Thoman (Ed.), *Origins of the infant's social responsiveness* (pp. 225–249). Hillsdale: Erlbaum

¹³ This is my own formulation of Nagel's reducibility definition, adapted from Nagel in *The Structure of Science* (1961) and Esfeld and Sachse in "Theory Reduction by Means of Functional Sub-Types" (2007).

¹⁴ Nagel's definition of reduction is often said to entail a *supervenience* relation. A set of facts (A-facts) logically supervene on another set of facts (B-facts) just in case B-facts determine A-facts. B-facts are said to "fix" A-facts, in so much as there will never be a change in A-facts without there also being an underlying change in B-facts.

¹⁵ Notice that (Δ) deals strictly with how we might come to *know* a theory by *knowing* another theory. In this way, Nagel's definition of theory reduction is epistemological, or nomological – i.e. it is concerned only with our knowledge of the two theories.

¹⁶ The antireductionist implications of MR have been enumerated fully in a somewhat different field of study – namely, the philosophy of mind. The discussion of MR arose in response to attempts to reduce psychological states to physical, neurological states. Jerry A. Fodor talks about the plausibility of reduction in science in general, and in philosophy of mind in particular, in "Special Sciences (Or: The Disunity of

Science as a Working Hypothesis)” (*Synthese*, 1974). Philosopher Jaegwon Kim presents possibly the most famous account of the threat of multiple realizability in “Multiple Realization and the Metaphysics of Reduction” (*Philosophy and Phenomenological Research*: 1992). My goal is to apply Kim and Fodor’s arguments in philosophy of mind to the topic at hand – namely, the reduction of decision theory to evolutionary theory.

¹⁷ Of course, Cooper could reply by saying that both instantiations are only superficially different, and that they are actually the same, evolutionarily speaking. But he would then have to prove that the fitness values assigned to various decisions vary in direct proportion to the utility values – in every case, across all species. Given that there are such radical differences in modes of reproduction between different physical realizers, this seems like a daunting task.

¹⁸ The problem with disjunctive predicates in bridge laws is argued for much more thoroughly, albeit in a very different context, by Jaegwon Kim (1992, p. 141).

¹⁹ A recent article on theory-reduction by Esfeld and Sachse (2007) offers an interesting counter-point to my argument against the Reducibility Thesis. The paper posits one way in which theory reduction could overcome Kim’s ‘multiple realizability’ objection. Esfeld and Sachse suggest that “theory reduction by means of functional sub-types” may be possible. Perhaps future studies could inquire as to whether this “functional sub-type” reduction can be applied to our case at hand – namely, the reduction of decision theory under evolutionary biology.

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