Counterfactual Reasoning: How to Organize a Possible World

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Abstract

Counterfactual reasoning appears to be a universal phenomenon of human inference from childhood to adulthood, yet, the prevailing explanations seem able to capture only a limited aspect of the process and are in need of an overarching framework. We propose that David Lewis' *possible worlds* analysis offers a first approximation to such a framework and gives a psychologically plausible account of counterfactuals. It identifies the unique properties of our ability to reason from false assumptions—whether talking about pretense or revising our beliefs. Three experiments are offered to suggest the plausibility of this account.

Counterfactual Reasoning

Counterfactual or hypothetical reasoning is ubiquitous in human interaction. It ranges from children's pretense (Scott, Baron-Cohen, & Leslie, 1999), everyday regret for the past, planning for the future (Roese & Olson, 1995), revising our knowledge base (e.g., Elio & Pelletier, 1997), to testing hypotheses (Farris & Revlin, 1989). Theories or descriptions of how this type of reasoning is actually accomplished are as varied as the situations they describe. Models of pretense rely on broadly specified processes, such as activation of "possible world box", input from "belief box", etc. (e.g., Nichols & Stich, 2000). Social psychologists describe *tendencies* to uphill vs. downhill reasoning when considering how events could have been different (e.g., Kahneman & Miller, 1986; Kahneman & Tversky, 1982). Models of belief revision range from minimizing the number of discarded propositions (e.g.,Elio & Pelletier, 1997) to preferences for certain types of sentences (e.g.; Revlis, Lipkin, & Hayes, 1971). Models of reasoning emphasize semantic and inference procedures (e.g., Walsh & Byrne, 2002) or modal logic categories (e.g., Revlin, Cate, & Rouss, 2001). A proposal for the process of counterfactual reasoning that has only slightly been represented in research paradigms is one offered from philosophical writings by David Lewis (1973, 1986) in his proposal of Possible Worlds. Our purpose here is to explore the consequences of Lewis' possible worlds treatment for counterfactual judgments in a belief-revision paradigm. We begin by describing the paradigm and why it might be useful as well as some basic findings. Then we turn to a description of Lewis' *possible worlds* and how it might be useful in understanding the findings of at least the belief-revision paradigm.

Belief Revision Paradigm

When we conjecture about some hypothesis, whose truth is in doubt or when we consider the consequences of some conjecture for what we already know or believe, we are doing counterfactual or hypothetical reasoning (Revlis & Hayes, 1972). A formal definition would be *reasoning from false* assumptions (Chisholm, 1946; Rescher, 1964). Let us suppose that you have discovered a new creature--it lays eggs and can live under water for prolonged periods of time and has no external mammary teats. On the face of this evidence you believe the animal is a reptile and treat it that way. However, someone proposes that you should assume, for the sake of argument, that it is a mammal". To evaluate this conjecture, you might assemble some pertinent facts from your belief portfolio and add the new "fact" to it[1]:

(1) (a) All mammals have live births
(b) This creature lays eggs
(c) This creature is a reptile (not a mammal)
(d) Assume: this creature is a mammal

There are two inconsistencies here. First the assumption directly contradicts statement (c), which must now be labeled "false". Second, the assumption, when joined with statement (a), contradicts statement (b) [*If all mammals have live births and this creature is a mammal, then this creature must not lay eggs*]. Later we will refer to this as the **Generalist Path**. Alternately, if we join the assumption with statement (b), the two jointly contradict statement (a) [*This mammal lays eggs so not all mammals have live births*]. This will be referred to as the **Particularist Path**. Given that these assembled "facts" are the pertinent ones to be considered, how shall we resolve the inconsistency introduced by this assumption, which contradicts our beliefs (at least it contradicts the belief that this creature is a reptile)? This is not a toy problem. The characteristics of the creature in question in (1) are among those of the *platypus* whose inclusion in the category of mammals was

[1] Technically, the suppositions described here are belief-contravening in that they contradict an accepted assertion, but do not necessarily deny a long held statement of fact. The paradigmatic problems are called belief-contravening problems by Rescher (1964).

controversial and required at least 80 years of debate during the 19th century (Eco, 2000).

The logical problem with counterfactuals is that anything is allowed to follow from a false assumption (i.e., from a false antecedent of a conditional) (e.g., Chisholm, 1946). How do we constrain the consequences of counterfactuals so that they do not promiscuously overwhelm our knowledge base? There must be a natural way to solve these inconsistencies because counterfactual reasoning is universal and is even understood by people whose language does not have the syntactic markers that are cues to counterfactual in English (Au, 1983). If we did not have a natural way of constraining the inferences, such reasoning would be useless. Our goal then is to identify the tools that people naturally use to revise their beliefs in the face of an assumption that defies those beliefs.

Interest in counterfactuals by philosophers, futurists, and computer scientists is decades old (see Elio & Pelletier, 1997 for a partial summary), but only a few of these projects addressed the question of how people actually interpret and act-upon counterfactuals (e.g., Rescher, 1964; Revlis, 1974; Simon & Rescher, 1966). In the past few years three quite different proposals have surfaced, each of which capture some aspect of how we treat counterfactuals. A logical analysis has been proposed by Byrne and her colleagues (e.g., Byrne & *, 1999; Byrne & Walsh, 2002; Thompson & Byrne, 2002), where counterfactuals are treated as a type of conditional reasoning. Her data suggest that people apply the same inference procedures to draw conclusions from counterfactuals conditionals as they do from indicative conditionals, except that the former are said to engender a richer representation in that they include more possible states of affairs (i.e., models). A different view of counterfactuals is represented by Dieussaert (e.g., Dieussaert, Schaeken, De Neys, & d'Ydewalle, 2000; Dieussaert, Schaeken, & d'Ydewalle, 2002). She reformulates counterfactuals as an example of belief-revision that fits within the broader context of defeasible reasoning (see also Elio & Pelletier, 1997). The third view is one that we advocate (e.g., Revlis & Hayes, 1972; Revlin, Cate, & Rouss, 2001). It sees counterfactual reasoning as a departure from standard conditional inference. Counterfactuals are *not* mere conditionals. The purpose of considering a counterfactual assumption is to challenge prevailing facts and beliefs. We propose that counterfactuals are usefully described by modal logic (Rescher, 1964) and that the vehicle for evaluating counterfactuals is to construct *possible worlds* (Lewis, 1986).

Experiment 1

Method and Procedure

To illustrate the natural resolution of counterfactuals, and that it does not readily follow rules of standard deduction, we gave 24 problems similar to (1) above to 28 university undergraduates (average age, 19) and to 18 elderly residents of a retirement community (average age, 70). Half of the problems had affirmatively expressed statements (e.g., *All whales are mammals*) and half had negative statements (e.g., *No whales are reptiles*). Participants were shown a sample problem that required no special knowledge of classes (e.g., *All trees on the town square are elms, suppose that this pine is a tree on the town square*) and they considered the two primary paths to creating consistency on this problem.

Results and Discussion

The percentage of people that selected the general solution (illustrated above) is presented in Table 1, which shows that for problems similar to (1) (called "combining"), most people prefer to retain the general statement and discard the specific fact significantly more often than chance. We note that elderly participants retain the generalities less often than do the university undergraduates [$F(1,44)=7.1$, $p=.01$]. Overall, reasoners did not distinguish between affirmatives and negatively expressed statements.

This preference for resolving inconsistencies by retaining scientific generalizations may be the reason that it required nearly a century to include the platypus and other *monotremes* into the class of *mammal* and therefore adjust the characteristics of that class.

Table 1: Percentage selecting the generalist path.

	Combining (1)	Rending (2)
University Students	91.4	21.4
Older Adults	79.7	18.3

Experiment 2

It might be conjectured that the people are simply choosing to retain the statements that they most believe. So that, people choose the generalist path because the generality is already known to be true across time and space (i.e., a scientific law), whereas the specific fact might be based on a single observation. Alternately, the reasoner solving such a problem has no particular belief in the fact—it's new to the belief system. We tested for this possibility in Experiment 2.

Method and Procedure

The same set of statements of Experiment 1can be re-arranged as in (2) where the counterfactual assumption (d) removes a member from a class (rather than adds a new member to a class). We call these types of problems Rending counterfactuals:

(2) (a) All mammals have live births
(b) This creature has live births
(c) This creature is a mammal
(d) Assume: this creature lays eggs (not live births)

The choices are basically the same for the reasoner under the counterfactual assumption in (1) and (2); that this,

creature, which is already a member of the class *mammal*, does not have one of its definitional properties (circa 19th century). These types of problems were shown to 25 undergraduate and 17 elderly participants from the same sample as included in Experiment 1. If believability is the mode of reasoning, then we should see the same pattern with Rending counterfactuals as we do for Combining ones.

Results and Discussion

These preferences are also presented in Table 1, which shows that Rending counterfactuals are not treated the same as Combining counterfactuals. Both groups of participants *rejected* the generality reliably more often than chance ($p<.001$). Although the overall percentage of elderly participants selecting the generalist path is less than for the students, the pattern is the same. The important thing to notice is that a commitment to the pre-conjectural truth of a statement seems to have little to do with how people resolve inconsistencies as a result of accepting a counterfactual assumption. This has been supported by the findings in other studies, where none of the statements has a belief value and yet the reasoners use the same strategy in solving the problems that they use in (1) above (Politzer & Carles, 2001; Redding-Stewart & Revlin, 1978; Revlis, 1974; Revlis & Hayes, 1972).

How Shall We Account For Counterfactuals? Lewis described at least six principles involved in the use of possible worlds that would both constrain and clarify contrary-to-fact conditionals (Lewis, 1986). We advocate the consideration of three of these principles (re-numbered here). *Principle 1* is that when considering a supposition, you select a possible world in which that statement is true in order to appreciate the consequences of it. The usefulness of this principle is not restricted to philosophy, it is also effective for understanding pretense behavior in children. Consider the process model of Nichols and Stich (2000): pretense behavior is initiated by the introduction into consciousness of a proposition that requires a possible world. This proposition in the "possible world box" connects with the child's belief system and activates necessary facts to allow the proposition to function and which inhibits antagonistic propositions. In the case where the child puts a banana to her ear and starts to speak to it as if it were a telephone (e.g., Leslie, 1987), many possible "speaking on the phone" scripts may be activated, but eating the banana, *qua phone* has to be inhibited or the pretense is over (O'Brien, Dias, Roazzi, & Braine, 1998). You can't have two possible worlds functioning with equal priority.

Which of the limitless possible worlds should be selected? The answer is dependent on the individual reasoner and can account for the diversity of conclusions drawn to counterfactuals. In response, *Principle 2* states that when you entertain a counterfactual assumption, you select the *closest* possible world—not just any world. We are free, however, to select the attributes on which the comparison of the worlds is made (i.e., the facts at hand). In the research presented here, we provide the salient facts for the reasoners to consider, but left on their own, they are free to fill the universe of discourse in anyway they wish (see also Thompson & Byrne, 2002). Take the following whimsical example as an illustration that there can be alternative possible worlds considered:

> A man asked the speaker: "How many home runs would Hank Aaron score in a season with today's watered-down pitching?"
>
> "40 or 50", was the reply.
>
> "How can you say that?" the man argued. "Aaron hit 755 home run and was the greatest home run hitter who ever lived."
>
> "You've got to remember," said the speaker, "the man is 69 years old."[2]

The findings of Experiments 1 and 2 show that reasoners across a substantial age span exhibit a consistent pattern for combining counterfactuals: they prefer to organize the belief space top-down, retaining the most law-like statements and rejecting others that are inconsistent with the union of the general statement and the assumption. This is in keeping with Lewis' *Principle 3*, the Principle of Modality: in the present world and in all possible worlds, the same modal logic holds. Modal logic specifies that statements may be characterized in term of degrees of necessity ranging from necessary truths (e.g., scientific laws and definitions: *all whales are mammals*) down to accidental generalizations (e.g., *all the coins in my pocket are made of silver*) (Goodman, 1955). Modal logic also specifies rules of inference that may be used to derive which conclusions are *necessarily* true and which are *possibly* true.

We propose that under the counterfactual assumption, the reasoner entertains a *possible world* workspace where the facts are organized by modal logic (Rescher, 1964), which offers a metric to resolve inconsistencies. Rescher (1964), whose treatment of counterfactuals pre-dated Lewis, described how the logic of modals could be used to organize any hypothetical domain (read that *possible world* workspace). For example, a sensible principle would be to arrange statements in terms of degrees of necessity. The counterfactual supposition should be joined with all operative laws. Those beliefs or statements that would be inconsistent with the union of these necessary modals would be eliminated (e.g., if previously believed to be *true*, their truth value would be changed to *false*). We believe that this application of modal logic is what we witness when students are asked to accept an assumption that combines two classes that previously are not connected.

[2] Not to put too fine a point on it, but the example illustrates that the possible world can be today with Aaron batting as he is currently constituted. Or the world could be today, but with Aaron as he was 40 years ago.

The decisions that occur when the assumption disconnects (i.e., rends) two classes that previously had a superset-subset relation are more equivocal. These are the Rending counterfactuals described in (2). Both Rescher and Lewis would argue that modal logic must apply here as well. Retrospective reports of students indicate that the supposition for these problems are perceived as a direct "attack" on the general proposition and make it seem less of a law and more of an empirical generalization. In this case, its modal status is reduced and it is, for some of the reasoners, not an organizing principle operative in the possible world. Hence, fewer people take the generalist path on these problems.

Of all the constraints on the use of possible worlds advocated by Lewis, Principle 1 is the most critical to our treatment of counterfactuals. It proclaims that counterfactual reasoning begins with the selection of a possible world in which the assumption is true. If the reasoner does not employ possible world logic, then we have no expectation of the path through these problems. Reasoners might opt to select the generalist or particularist path roughly equally on these problems, as observed by Byrne and Walsh (2002), or the particularist path that was reported by Elio and Pelletier (1997).

What would happen if Principle 1 is irrelevant to counterfactual reasoning and the pre-existing state of affairs did not have an effect on the resolution path chosen by people? If Principle 1 is not operative, then the resolution procedures may be the ones that are consistent with procedures applied to drawing inferences from indicative conditionals, as described by mental models theory. Therefore, we would agree that if Principle 1 is irrelevant, then the entire enterprise of employing possible world formalism will not contribute much to our understanding of counterfactuals.

In Experiments 1 and 2, reasoners are instructed to first certify that the beliefs (i.e., the facts in question) form a consistent set. This latter procedures lends some coherence to the set of statements that may correspond to the "current world". Reasoners then have to consider the implications of the counterfactual. We believe that in our paradigm there is a clear division between the old belief system and the new, which heightens the requirement to consider a second, possible world. If this sensitivity to the pre-existing state of affairs is not present, then possible worlds logic would not need to be applied and reasoners would be free to use believability or conditional reasoning procedures to resolve inconsistencies.

Experiment 3

Method and Procedure

This experiment contrasts the two paradigms just described by examining the reasoning patterns of students sampled from the same introductory psychology cohort. There were four groups of participants. Two groups (n=60) constituted the Inference Condition. They either solved problems similar to (1) or (2) above except that they were not instructed to certify "pre-assumption" consistency nor did they see a statement that directly contradicted the assumption (e.g., statements 1c or 2b). In this way the counterfactual assumption was just one of a set of statements, and was unique only in the sense that the letter "T" appeared next to it indicating that the reasoners should treat it as *true*.

Two other groups (n=50) consisted of participants from the same course. They solved (1) or (2) type problems. They first were to assure themselves that the first three sentences were consistent, and then they were to consider the impact of the counterfactual (which they had to assume was *true*).This was a replication of previous findings.

Results and Discussion

The students in the Inference condition, overwhelming preferred to reconcile inconsistencies by retaining the most general statement. The percentages are shown in Table 2. They indicate that reasoners in this condition do not distinguish between combining and rending counterfactuals and simply select the general statement as their starting point and reject the particular statement.

In contrast, the students who were presented with two distinct conditionals (called the Two World conditions in Table 2) showed an elevated preference for reasoning with the generality when they were confronted with Combining counterfactuals, but were not reliably above chance in the preferences with Rending counterfactuals. This is just what is anticipated by the possible worlds/modal logic analysis..

Table 2: Percent selecting the generalist path

Paradigm	Combining (1)	Rending (2)
Inference condition	77.1	80.1
Two world condition	85.7	61.0

General Discussion

Three principles offered by Lewis are manifested in the data of students reconciling inconsistencies that are introduced by counterfactual conditionals. Principle 1 says that people will take the supposition and will automatically activate a possible world. Principle 2 states that this world will include the relevant facts at hand so that the two worlds will be as similar as possible. Finally, Principle 3 claims that the possible world will be organized along the lines of modal logic, where statements can be arranged in terms of degrees of necessity. It is a top-down world that dictates which statements will be retained and which will be rejected. The findings of the studies presented here fit nicely with the pattern predicted from the three principles.[3] Experiment 3

[3] Principle 2 is not assessed here. It allows for differing interpretations of what constitutes the facts at hand by different reasoners.

shows that reasoners are doing something special over and above predicate calculus (or reading-off a mental model) when they consider the counterfactual assumption. Experiments 1 and 2 illustrate that there is a distinct path that reasoners select and this is in line with the predictions of a modal logic assessment of counterfactual reasoning. Stated differently, if the reasoner treats the assumption and in conflict with a prior state of affairs, then it will be treated as a counterfactual. If the assumption is viewed as merely one of a set of statements that needs to be made consistent, then the reasoning process will be sensitive to believability or to standard logical procedures.

These principles are not restricted to the paradigms described here. For example, the notion of possible worlds plays a role in treatments of pretense in children. Some acknowledgment of this is seen in the theory proposed by Nichols and Stich (2001) and others (e.g., Lillard, 2001).

One of the many forms of counterfactual reasoning occurs in situations of *regret* or what might be called *upward reasoning* (e.g., German, 1999), in which counterfactuals are employed to simulate an undesirable past and to see how it could have been made better.[4] Kahneman and Tversky (1982) in initiating this line of research identify two aspects of the reasoning that bears on the present proposal. First, in support of Principle 2, they note that the reasoners differ on which events they would change as a function of their perspective or point-of-view manipulated in the scenarios. However, Kahneman and Tversky appear to contradict Principle 3: they identify what they consider to be the dominant reasoning strategy, *downhill reasoning*, which is the tendency to avoid changing the least probable event. On the face of it, this strategy violates Principle 3 because a modal analysis of conditions should seek to retain the most necessary events at the expense of the contingent ones. Kahneman and Tversky (1982) found that when people try to imagine how a traffic accident scenario could have been "better", only a minority of them alters the accident itself (a low probable event). This is sensible, however, if the reasoners view the traffic accident as part of the supposition to which they are committed and which, therefore, cannot, on the face of it, be defined away. Rather than violating Principle 3, they are acknowledging the demarcation between the present world and the possible.

Decoupling

The Possible Worlds perspective is evaluated here for its ability to give some coherence to counterfactual reasoning. But it is not merely useful. The concept of possible worlds or something of its genre is absolutely necessary to account for the natural use of counterfactuals. This is because when we imagine a future situation or re-imagine an old one, or create a hypothesis to be tested, the propositions that we consider must not contaminate our database of personal knowledge because such information "may be false, misleading or harmful". They must be *decoupled* from what we know (Cosmides & Tooby, 2000). We must have a mechanism that labels propositions as *belief*, *conjecture*, *hearsay*, etc. lest we add the statements themselves or the inferences that we derive from them to our knowledge base. A formalism that can accomplish this separation and keep track of our inferences and their dependencies is to compute such inferences in a, possible world workspace, which can be as real as the "real" one, but separate.

[4] We note that simulated conditions in that paradigm are not strictly, pre-experimental beliefs held by the reasoners. They too are belief-contravening.

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