Timeless Decision Theory

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Table of Contents

1: Short abstract

Disputes between evidential decision theory and causal decision theory have continued for decades, and many theorists state dissatisfaction with both alternatives. Timeless decision theory (TDT) is an extension of causal decision networks that compactly represents uncertainty about correlated computational processes and represents the decision-maker as such a process. This simple extension enables TDT to return the one-box answer for Newcomb's Problem, the causal answer in Solomon's Problem, and mutual cooperation in the one-shot Prisoner's Dilemma, for reasons similar to human intuition. Furthermore, an evidential or causal decision-maker will choose to imitate a timeless decision-maker on a large class of problems if given the option to do so.

2: Long abstract

Disputes between evidential decision theory and causal decision theory have continued for decades, with many theorists stating that neither alternative seems satisfactory. I present an extension of decision theory over causal networks, timeless decision theory (TDT). TDT compactly represents uncertainty about the abstract outputs of correlated computational processes, and represents the decision-maker's decision as the output of such a process. I argue that TDT has superior intuitive appeal when presented as axioms, and that the corresponding causal decision networks (which I call timeless decision networks) are more true in the sense of better representing physical reality. I review Newcomb's Problem and Solomon's Problem, two paradoxes which are widely argued as showing the inadequacy of causal decision theory and evidential decision theory respectively. I walk through both paradoxes to show that TDT achieves the appealing consequence in both cases. I argue that TDT implements correct human intuitions about the paradoxes, and that other decision systems act oddly

because they lack representative power. I review the Prisoner's Dilemma and show that TDT formalizes Hofstadter's "superrationality": under certain circumstances, TDT can permit agents to achieve "both C" rather than "both D" in the one-shot, non-iterated Prisoner's Dilemma. Finally, I show that an evidential or causal decision-maker capable of self-modifying actions, given a choice between remaining an evidential or causal decision-maker and modifying itself to imitate a timeless decision-maker, will choose to imitate a timeless decision-maker on a large class of problems.

3: Some Newcomblike problems

Newcomb's Problem:

Imagine that a superintelligence from another galaxy, whom we shall call the Predictor, comes to Earth and at once sets about playing a strange and incomprehensible game. In this game, the superintelligent Predictor selects a human being, then offers this human being two boxes. The first box, Box A, is transparent and contains a thousand dollars. The second box, Box B, is opaque and contains either a million dollars or nothing. You may take only box B, or you may take boxes A and B. But there's a twist: *If* the superintelligent Predictor thinks that you'll take both boxes, the Predictor has left box B empty; and you will receive only a thousand dollars. If the Predictor thinks that you'll take only box B, then It has placed a million dollars in box B. Before you make your choice, the Predictor has already moved on to Its next game; there is no possible way for the contents of box B to change after you make your decision. If you like, imagine that box B has no back, so that your friend can look inside box B, though she can't signal you in any way. Either your friend sees that box B already contains a million dollars, or she sees that it already contains nothing. Imagine that you have watched the Predictor play a thousand such games, against people like you, some of whom two-boxed and some of whom one-boxed, and on each and every occasion the Predictor has predicted accurately. Do you take both boxes, or only box B?

This puzzle is known as Newcomb's Problem or Newcomb's Paradox. It was devised by the physicist William Newcomb, and introduced to the philosophical community by Robert Nozick (1969).

The resulting dispute over Newcomb's Problem split the field of decision theory into two branches, *causal decision theory* (CDT) and *evidential decision theory* (EDT).

The evidential theorists would take only box B in Newcomb's Problem, and their stance is easy to understand. Everyone who has previously taken both boxes has received a mere thousand dollars, and everyone who has previously taken only box B has received a million dollars. This is a simple dilemma and anyone who comes up with an elaborate reason why it is "rational" to take both boxes is

just outwitting themselves. The "rational" chooser is the one with a million dollars.

The causal theorists analyze Newcomb's Problem as follows: Because the Predictor has already made Its prediction and moved on to Its next game, it is *impossible* for your choice to affect the contents of box B in any way. Suppose you knew for a fact that box B contained a million dollars; you would then prefer the situation where you receive both boxes ($1,001,000) to the situation where you receive only box B ($1,000,000). Suppose you knew for a fact that box B were empty; you would then prefer to receive both boxes ($1,000) to only box B ($0). Given that your choice is *physically incapable* of affecting the content of box B, the rational choice must be to take both boxes - following the *dominance principle,* which is that if we prefer A to B given X, and also prefer A to B given ~X (not-X), and our choice cannot *causally affect* X, then we should prefer A to B. How then to explain the uncomfortable fact that evidential decision theorists end up holding all the money and taking Caribbean vacations, while causal decision theorists grit their teeth and go on struggling for tenure? According to causal decision theorists, the Predictor has chosen to reward people for being irrational; Newcomb's Problem is no different from a scenario in which a superintelligence decides to arbitrarily reward people who believe that the sky is green. Suppose you could make yourself believe the sky was green; would you do so in exchange for a million dollars? In essence, the Predictor offers you a large monetary bribe to relinquish your rationality.

What would you do?

The split between *evidential decision theory* and *causal decision theory* goes deeper than a verbal disagreement over which boxes to take in Newcomb's Problem. Decision theorists in both camps have formalized their arguments and their decision algorithms, demonstrating that their different *actions* in Newcomb's Problem reflect different *computational algorithms* for choosing between actions.[1] The evidential theorists espouse an algorithm which, translated to English, might read as "Take actions such that you would be glad to receive the news that you had taken them." The causal decision theorists espouse an algorithm which, translated to English, might cash out as "Take actions which you expect to have a positive physical effect on the world."

The decision theorists' dispute is not just about trading arguments within an informal, but shared, common framework - as is the case when, for example, physicists argue over which hypothesis best explains a surprising experiment. The causal decision theorists and evidential decision theorists have offered different mathematical frameworks for *defining* rational decision. Just as the evidential decision theorists walk off with the money in Newcomb's Problem, the causal decision theorists offer their own paradox-arguments in which the causal decision theorist "wins" - in which the causal decision algorithm produces the

[1] I review the algorithms and their formal difference in section 5.

action that would seemingly have the better real-world consequence. And the evidential decision theorists have their own counterarguments in turn.

Solomon's Problem:

Variants of Newcomb's problem are known as Newcomblike problems. Here is an example of a Newcomblike problem which is considered a paradox-argument favoring causal decision theory. Suppose that a recently published medical study shows that chewing gum seems to cause throat abscesses - an outcome-tracking study showed that of people who chew gum, 90% died of throat abscesses before the age of 50. Meanwhile, of people who do not chew gum, only 10% die of throat abscesses before the age of 50. The researchers, to explain their results, wonder if saliva sliding down the throat wears away cellular defenses against bacteria. Having read this study, would you choose to chew gum? But now a second study comes out, which shows that most gum-chewers have a certain gene, CGTA, and the researchers produce a table showing the following mortality rates:

	Chew gum	Don't chew gum
CGTA present:	89% die	99% die
CGTA absent:	8% die	11% die

This table shows that whether you have the gene CGTA or not, your chance of dying of a throat abscess goes *down* if you chew gum. Why are fatalities so much higher for gum-chewers, then? Because people with the gene CGTA tend to chew gum *and* die of throat abscesses. The authors of the second study also present a test-tube experiment which shows that the saliva from chewing gum can kill the bacteria that form throat abscesses. The researchers hypothesize that because people with the gene CGTA are highly susceptible to throat abscesses, natural selection has produced in them a tendency to chew gum, which protects against throat abscesses[2]. The strong correlation between chewing gum and throat abscesses is not because chewing gum *causes* throat abscesses, but because a third factor, CGTA, leads to chewing gum *and* throat abscesses.

Having learned of this new study, would you choose to chew gum? Chewing gum helps protect against throat abscesses whether or not you have the gene CGTA. Yet a friend who heard that you had decided to chew gum (as people with the gene CGTA often do) would be quite alarmed to hear the news - just as

[2] One way in which natural selection could produce this effect is if the gene CGTA persisted in the population - perhaps because it is a very common mutation, or because the gene CGTA offers other benefits to its bearers which renders CGTA a slight net evolutionary advantage. In this case, the gene CGTA would be a feature of the genetic environment which would give an advantage to other genes which mitigated the deleterious effect of CGTA. For example, in a population pool where CGTA is often present as a gene, a mutation such that CGTA (in addition to causing throat cancer) also switches on other genes which cause the CGTA-bearer to chew gum, will be advantageous. The end result would be that a single gene, CGTA, could confer upon its bearer both a vulnerability to throat cancer and a tendency to chew gum.

she would be saddened by the news that you had chosen to take both boxes in Newcomb's Problem. This is a case where evidential decision theory seems to return the wrong answer, calling into question the validity of the evidential rule "Take actions such that you would be glad to receive the news that you had taken them". Although the *news* that someone has decided to chew gum is alarming, medical studies nonetheless show that chewing gum protects against throat abscesses. Causal decision theory's rule of "Take actions which you expect to have a positive physical effect on the world" seems to serve us better.[3]

The CGTA dilemma is an essentially identical variant of a problem first introduced by Nozick in his original paper, but not then named. Presently this class of problem seems to be most commonly known as Solomon's Problem after Gibbard and Harper (1978), who presented a variant involving King Solomon. In this variant, Solomon wishes to send for another man's wife[4]. Solomon knows that there are two types of rulers, charismatic and uncharismatic. Uncharismatic rulers are frequently overthrown; charismatic rulers are not. Solomon knows that charismatic rulers rarely send for other people's spouses and uncharismatic rulers often send for other people's spouses, but Solomon also knows that this does not *cause* the revolts - the reason uncharismatic rulers are overthrown is that they have a sneaky and ignoble bearing. I have substituted the chewing-gum throat-abscess variant of Solomon's Problem because, in real life, we do *not* say that such deeds are causally independent of overthrow. Similarly there is another common variant of Solomon's Problem in which smoking does not cause lung cancer, but rather there is a gene that both causes people to smoke and causes them to get lung cancer (as the tobacco industry is reputed to have once argued could be the case). I have avoided this variant because in real life, smoking does cause lung cancer. Research in psychology shows that people confronted with logical syllogisms possessing common-sense interpretations often go by the common-sense conclusion instead of the syllogistic conclusions. Therefore I have chosen an example, chewing gum and throat abscesses, which does not conflict with a pre-existing picture of the world.

Nonetheless I will refer to this *class* of problem as Solomon's Problem, in accordance with previous literature.

Weiner's Robot Problem:

A third Newcomblike problem from (Weiner 2004): Suppose that your friend falls down a mineshaft. It happens that in the world there exist robots, conscious robots, who are in most ways indistinguishable from humans. Robots are so indistinguishable from humans that most people do not know whether they are robots or humans. There are only two differences between robots and humans.

[3] There is a formal counter-argument known as the "tickle defense" which proposes that evidential decision agents will also decide to chew gum; but the same tickle defense is believed (by its proponents) to choose two boxes in Newcomb's Problem. See section 11.

[4] Gibbard and Harper gave this example invoking King Solomon after first describing another dilemma involving King David and Bathsheba.

First, robots are programmed to rescue people whenever possible. Second, robots have special rockets in their heels that go off only when necessary to perform a rescue. So if you are a robot, you can jump into the mineshaft to rescue your friend, and your heel rockets will let you lift him out. But if you are not a robot, you must find some other way to rescue your friend - perhaps go looking for a rope, though your friend is in a bad way, with a bleeding wound that needs a tourniquet *now...* Statistics collected for similar incidents show that while all robots decide to jump into mineshafts, nearly all humans decide not to jump into mineshafts. Would you decide to jump down the mineshaft?

Nick Bostrom's Meta-Newcomb Problem:

A fourth Newcomblike problem comes from Bostrom (2001), who labels it the Meta-Newcomb problem. In Nick Bostrom's Meta-Newcomb problem you are faced with a Predictor who may take one of two possible actions: Either the Predictor has *already* made Its move - placed a million dollars or nothing in box B, depending on how It predicts your choice - or else the Predictor is watching to see your choice, and will *afterward,* once you have irrevocably chosen your boxes, but before you open them, place a million dollars into box B if and only if you have not taken box A. If you know that the Predictor observes your choice *before* filling box B, there is no controversy - any decision theorist would say to take only box B. Unfortunately, there is no way of knowing; the Predictor makes Its move before or after your decision around half the time in both cases. Now suppose there is a Meta-Predictor, who has a perfect track record of predicting the Predictor's choices and also your own. The Meta-Predictor informs you of the following truth-functional prediction: *Either* you will choose A and B, and Predictor will make Its move after you make your choice; *or else* you will choose only B, and Predictor has already made Its move.

An evidential decision theorist is unfazed by Nick Bostrom's Meta-Newcomb Problem; he takes box B and walks away, pockets bulging with a million dollars. But a causal decision theorist is faced with a puzzling dilemma: If she takes boxes A and B, then the Predictor's action depends physically on her decision, so the "rational" action is to take only box B. But if she takes only box B, then the Predictor's action temporally precedes and is physically independent of her decision, so the "rational" action is to take boxes A and B.

Decision theory

It would be unfair to accuse the field of decision theory of being polarized between evidential and causal branches, even though the computational algorithms seem incompatible. Nozick, who originally introduced the Newcomb problem to philosophy, proposes that a prudent decision-maker should compute both evidential and causal utilities and then combine them according to some weighting (Nozick 1969). Egan (2007) lists what he feels to be fatal problems for

both theories, and concludes by hoping that some alternative formal theory will succeed where both causal and evidential decision theory fail.[5]

In this paper I present a novel formal foundational treatment of Newcomblike problems, using an augmentation of Bayesian causal diagrams. I call this new representation "timeless decision diagrams".

From timeless decision diagrams there follows naturally a timeless decision algorithm, in whose favor I will argue; however, using timeless decision diagrams to analyze Newcomblike problems does not commit one to espousing the timeless decision algorithm.

4: Precommitment and dynamic consistency.

Nozick, in his original treatment of Newcomb's Problem, suggested an agenda for further analysis - in my opinion a very insightful agenda, which has been often (though not always) overlooked in further discussion. This is to analyze the *difference* between Newcomb's Problem and Solomon's Problem that leads to people advocating that one should use the dominance principle in Solomon's Problem but not in Newcomb's Problem.

In the chewing-gum throat-abscess variant of Solomon's Problem, the dominant action is chewing gum, which leaves you better off whether or not you have the CGTA gene; but choosing to chew gum is *evidence* for possessing the CGTA gene, although it cannot *affect* the presence or absence of CGTA in any way. In Newcomb's Problem, causal decision theorists argue that the dominant action is taking both boxes, which leaves you better off whether box B is empty or full; and your physical press of the button to choose only box B or both boxes cannot change the predetermined contents of box B in any way. Nozick says:

> "I believe that one should take what is in both boxes. I fear that the considerations I have adduced thus far will not convince those proponents of taking only what is in the second box. Furthermore, I suspect that an adequate solution to this problem will go much deeper than I have yet gone or shall go in this paper. So I want to pose one question... The question I should like to put to proponents of taking only what is in the second box in Newcomb's example (and hence not performing the dominant action) is: what is the difference between Newcomb's example and the other two examples [of Solomon's Problem] which make the difference between not following the dominance principle and following it?
>
> "If no such difference is produced, one should not rush to conclude that one should perform the dominant action in Newcomb's example. For it must be granted that, at the very least, it is not *as clear* that one should perform the dominant action in Newcomb's example as in the other two examples. And

[5]There have been other decision theories introduced in the literature as well, e.g. in (Arntzenius 2002), (Aumann et al. 1996), and (Drescher 2006).

> one should be wary of attempting to force a decision in an unclear case by producing a similar case where the decision is clear and challenging one to find a difference between the cases which makes a difference to the decision. For suppose the undecided person, or the proponent of another decision, cannot find such a difference. Does not the forcer now have to find a difference between the cases which explains why one is clear and the other is not?"

What is the key difference between chewing gum that is evidence of susceptibility to throat abscesses, and taking both boxes which is evidence of box B's emptiness? Most two-boxers argue that there is no difference. Insofar as two-boxers analyze the seeming difference between the two Newcomblike problems, they give *deflationary* accounts, analyzing a *psychological illusion* of difference between two structurally identical problems. E.g. Gibbard and Harper (1978) say in passing: "The Newcomb paradox discussed by Nozick (1969) has the same structure as the case of Solomon."

I will now present a preliminary argument that there is a significant structural difference between the two cases:

Suppose that *in advance* of the Predictor making Its move in Newcomb's Problem, you have the ability to *irrevocably resolve* to take only box B. Perhaps, in a world filled with chocolate-chip cookies and other harmful temptations, humans have finally evolved (or genetically engineered) a mental capacity for sticking to diets - making resolutions which, once made, automatically carry through without a chance for later reconsideration. Newcomb's Predictor predicts an irrevocably resolved individual as easily as It predicts the undecided psyche.

A causal decision agent has every right to expect that if he irrevocably resolves to take only box B *in advance* of the Predictor's examination, this directly causes the Predictor to fill box B with a million dollars. All decision theories agree that in this case it would be rational to precommit yourself to taking only box B - even if, afterward, causal decision agents would wistfully wish that they had the option to take both boxes, once box B's contents were fixed. Such a firm resolution has the same effect as pressing a button which locks in your choice of only B, in *advance* of the Predictor making Its move.

Conversely in the CGTA variant of Solomon's Problem, a causal decision agent, knowing in advance that he would have to choose between chewing gum and avoiding gum, has no reason to precommit himself to avoiding gum. This is a difference between the two problems which suggests that they are not structurally equivalent from the perspective of a causal decision agent.

Edward McClennen (1985) analyzes cases where an agent may wish to precommit himself to a particular course of action. McClennen gives the

example of two players, Row and Column, locked in a non-zero-sum game with the following move/payoff matrix:

Payoffs are presented as (Row, Column). Column moves second.

		Column:	
		No-U	U
Row:	No-D	(4,3)	(1,4)
	D	(3,1)	(2,2)

Whether Row makes the move No-D or D, Column's advantage lies in choosing U. If Row chooses No-D, then U pays 4 for Column and No-U pays 3. If Row chooses D, then U pays 2 for Column and No-U pays 1. Row, observing this dominance, assumes that Column will play U, and therefore plays the move D, which pays 2 to Row if Column plays U, as opposed to No-D which pays 1.

This outcome (D, U) = (2, 2) is not a Pareto optimum. Both Row and Column would prefer (No-D, No-U) to (D, U). However, McClennen's Dilemma differs from the standard Prisoner's Dilemma in that D is *not* a dominating option for Row. As McClennen asks: "Who is responsible for the problem here?" McClennen goes on to write:

> "In this game, Column cannot plead that Row's disposition to non-cooperation requires a security-oriented response of U. Row's maximizing response to a choice of No-U by Column is No-D, not D... Thus, it is Column's own maximizing disposition so characterized that sets the problem for Column."

McClennen then suggests a scenario in which Column can pay a *precommitment cost* which forestalls all possibility of Column playing U. "Of course," says McClennen, "such a precommitment device will typically require the expenditure of some resources." Perhaps the payoff for Column of (No-D, No-U) is 2.8 instead of 3 after precommitment costs are paid.

McClennen cites the Allais Paradox as a related single-player example. The Allais Paradox (Allais 1953) illustrates one of the first *systematic biases* discovered in the human psychology of decision-making and probability assessment, a bias which would later be incorporated in the heuristics-and-biases program (Kahneman et al. 1982). Suppose that you must choose between two gambles A and B with these payoff[6] probabilities:

A: 33/34 probability of paying $2,500, 1/34 probability of paying $0.
B: Pays $2,400 with certainty.

[6] Since the Allais paradox dates back to the 1950s, a modern reader should multiply all dollar amounts by a factor of 10 to maintain psychological parity.

Take a moment to ask yourself whether you would prefer A or B, if you had to play one and only one of these gambles. You need not assume your utility is linear in wealth - just ask which gamble you would prefer in real life. If you prefer A to B or vice versa, ask yourself whether this preference is strong enough that you would be willing to pay a single penny in order to play A instead of B or vice versa.

When you have done this, ask yourself about your preference over these two gambles:

C: ($2,500, 33/100; $0, 67/100)
D: ($2,400, 34/100; $0, 66/100)

Many people prefer B to A, but prefer C to D. This preference is called "paradoxical" because the gambles C and D equate precisely to a 34/100 probability of playing the gambles A and B respectively. That is, C equates to a gamble which offers a 34/100 chance of playing A, and D equates to a gamble which offers a 34/100 chance of playing B.

If an agent prefers B to A and C to D this potentially introduces a *dynamic inconsistency* into the agent's planning. Suppose that at 12:00PM I roll a hundred-sided die. If the die shows a number greater than 34 the game terminates. Otherwise, at 12:05PM I consult a switch with two settings, X and Y. If the setting is Y, I pay you $2,400. If the setting is X, I roll a 34-sided die and pay you $2,500 unless the die shows "34". If you prefer C to D and B to A and you would pay a penny to indulge each preference, your *preference reversal* renders you exploitable. Suppose the switch starts in state Y. Before 12:00PM, you pay me a penny to throw the switch to X. After 12:00PM and before 12:05PM, you pay me a penny to throw the switch to Y. I have taken your two cents on the subject.

McClennen speaks of a "political economy of past and future selves"; the past self must choose present actions subject to the knowledge that the future self may have different priorities; the future self must live with the past self's choices but has its own agenda of preference. Effectively the past self plays a non-zero-sum game against the future self, the past self moving first. Such an agent is characterized as a "sophisticated chooser". (Hammond 1976, Yaari 1977). Ulysses, faced with the tempting Sirens, acts as a sophisticated chooser; he arranges for himself to be bound to a mast. Yet as McClennen notes, such a strategy involves a retreat to second-best. Because of precommitment costs, sophisticated choosers will tend to do systematically worse than agents with no preference reversals. It is also usually held that preference reversal is inconsistent with expected utility maximization and indeed rationality. See (Kahneman and Tversky 2000) for discussion.

McClennen therefore argues that being a *resolute* agent is better than being a sophisticated chooser, for the resolute agent pays no precommitment costs. Yet it is better still to have no *need* of resoluteness - to decide using an algorithm which is invariant under translation in time. This would conserve mental energy. Such an agent's decisions are called *dynamically consistent* (Strotz 1956).

Consider this argument: "Causal decision theory is dynamically inconsistent because there exists a problem, the Newcomb Problem, which calls forth a need for resoluteness on the part of a causal decision agent."

A causal decision theorist may reply that the analogy between McClennen's Dilemma or Newcomb's Problem on the one hand, and the Allais Paradox or Ulysses on the other, fails to carry through. In the case of the Allais Paradox or Ulysses and the Sirens, the agent is willing to pay a precommitment cost because he fears a preference reversal from one time to another. In McClennen's Dilemma the source of Column's willingness to pay a precommitment cost is not Column's anticipation of a future preference reversal. Column prefers the outcome (Not-D, U) to (Not-D, Not-U) at both precommitment time and decision time. However, Column prefers that Row play Not-D to D - this is what Column will accomplish by paying the precommitment cost. For McClennen's Dilemma to carry through, the effort made by Column to precommit to Not-U must have *two* effects. First, it must cause Column to play Not-U. Second, Row must *know* that Column has committed to playing Not-U, so that Row's maximizing move is Not-D. Otherwise the result will be (D, Not-U), the worst possible result for Column. A purely mental resolution by Column might fail to reassure Row, thus leading to this worst possible result.[7] In contrast, in the Allais Paradox or Ulysses and the Sirens the problem is wholly self-generated, so a purely mental resolution suffices.

In Newcomb's Problem the causal agent regards his precommitment to take only box B as having *two* effects, the first effect being receiving only box B, and the second effect causing the Predictor to correctly predict the taking of only box B, hence filling box B with a million dollars. The causal agent always prefers receiving $1,001,000 to $1,000,000, or receiving $1000 to $0. Like Column trying to influence Row, the causal agent does not precommit in anticipation of a future preference reversal, but to influence the move made by Predictor. The apparent dynamic inconsistency arises from different *effects* of the decision to take both boxes when decided at different times. Since the effects significantly differ, the preference reversal is illusory.

When is a precommitment cost unnecessary, or a need for resoluteness a sign of dynamic inconsistency? Consider this argument: Paying a precommitment cost to decide at t_1 instead of t_2, or requiring an irrevocable resolution to implement at t_2 a decision made at t_1, shows dynamic inconsistency if agents who

[7] Column would be wiser to irrevocably resolve to play Not-U *if* Row plays Not-D. If Row knows this, it would further encourage Row to play appropriately.

precommit to a decision at time t_1 do just as well, no better and no worse excluding commitment costs, than agents who choose the same option at time t_2. More generally we may specify that for any agent who decides to take a fixed action at a fixed time, the experienced outcome is the same for that agent regardless of *when* the decision to take that action is made. Call this property *time-invariance* of the dilemma.

Time-invariance may not properly describe McClennen's Dilemma, since McClennen does not specify that Row *reliably predicts* Column regardless of Column's decision time. Column may need to take extra external actions to 'precommit' *in a fashion Row can verify;* the analogy to international diplomacy is suggestive of this. In Newcomb's Dilemma we are told that the Predictor is never or almost never wrong, in virtue of an excellent ability to extrapolate the future decisions of agents, precommitted or not. Therefore it would seem that, in observed history, agents who precommit to take only box B do no better and no worse than agents who choose on-the-fly to take only box B.

This argument only thinly conceals the root of the disagreement between one-boxers and two-boxers in Newcomb's Problem; for the argument speaks not of how an agent's deciding at T or T+1 *causes* or *brings about* an outcome, but only whether agents who decide at T or T+1 *receive* the same outcome. A causal decision theorist would protest that agents who precommit at T *cause* the desired outcome and are therefore rational, while agents who decide at T+1 merely *receive* the same outcome without doing anything to bring it about, and are therefore irrational. A one-boxer would say that this reply *illustrates* the psychological quirk which underlies the causal agent's dynamic inconsistency; but it does not make his decisions any less dynamically inconsistent.

Before dismissing the force of this one-boxing argument, consider the following dilemma, a converse of Newcomb's Problem, which I will call Newcomb's Soda. You know that you will shortly be administered one of two sodas in a double-blind clinical test. After drinking your assigned soda, you will enter a room in which you find a chocolate ice cream and a vanilla ice cream. The first soda produces a strong but entirely subconscious desire for chocolate ice cream, and the second soda produces a strong subconscious desire for vanilla ice cream. By "subconscious" I mean that you have no introspective access to the change, any more than you can answer questions about individual neurons firing in your cerebral cortex. You can only infer your changed tastes by observing which kind of ice cream you pick.

It so happens that all participants in the study who test the Chocolate Soda are rewarded with a million dollars after the study is over, while participants in the study who test the Vanilla Soda receive nothing. But subjects who actually *eat* vanilla ice cream receive an additional thousand dollars, while subjects who actually eat chocolate ice cream receive no additional payment. You can choose one and only one ice cream to eat. A pseudo-random algorithm assigns sodas to

experimental subjects, who are evenly divided (50/50) between Chocolate and Vanilla Sodas. You are told that 90% of previous research subjects who chose chocolate ice cream did in fact drink the Chocolate Soda, while 90% of previous research subjects who chose vanilla ice cream did in fact drink the Vanilla Soda.[8] Which ice cream would you eat?

Newcomb's Soda has the same structure as Solomon's Problem, except that instead of the outcome stemming from genes you possessed since birth, the outcome stems from a soda you will shortly drink. Both factors are in no way affected by your action nor by your decision, but your action provides *evidence* about which genetic allele you inherited or which soda you drank.

An evidential decision agent facing Newcomb's Soda will, *at the time of confronting the ice cream,* decide to eat chocolate ice cream because expected utility conditional on this decision exceeds expected utility conditional on eating vanilla ice cream. However, suppose the evidential decision agent is given an opportunity to precommit to an ice cream flavor *in advance*. An evidential agent would rather precommit to eating vanilla ice cream than precommit to eating chocolate, because such a precommitment made *in advance of drinking the soda* is not *evidence* about which soda will be assigned.

Thus, the evidential agent would rather precommit to eating vanilla, even though the evidential agent will prefer to eat chocolate ice cream if making the decision 'in the moment'. This would not be dynamically inconsistent if agents who precommitted to a future action received a different payoff than agents who made that same decision 'in the moment'. But in Newcomb's Soda you receive exactly the same payoff regardless of whether, in the moment of action, you eat vanilla ice cream because you precommitted to doing so, or because you choose to do so at the last second. Now suppose that the evidential decision theorist protests that this is not *really* a dynamic inconsistency because, even though the outcome is just the same for you regardless of when you make your decision, the decision has different *news-value* before the soda is drunk and after the soda is drunk. A vanilla-eater would say that this *illustrates* the psychological quirk which underlies the evidential agent's dynamic inconsistency, but it does not make the evidential agent any less dynamically inconsistent.

Therefore I suggest that time-invariance, for purposes of alleging dynamic inconsistency, should go according to invariance of the agent's *experienced outcome.* Is it not outcomes that are the ultimate *purpose* of all action and decision theory? If we exclude the evidential agent's protest that two decisions are not equivalent, despite identical outcomes, because at different times they possess different news-values; then to be fair we should also exclude the causal agent's protest that two decisions are not equivalent, despite identical outcomes, because at different times they bear different causal relations.

[8] Given the dumbfounding human capability to rationalize a preferred answer, I do not consider it implausible in the real world that 90% of the research subjects assigned the Chocolate Soda would choose to eat chocolate ice cream. (Kahneman et al. 1982)

Advocates of causal decision theory (which has a long and honorable tradition in academic discussion) may feel that I am trying to slip something under the rug with this argument - that in some subtle way I assume that which I set out to argue. In the next section, discussing the role of invariance in decision problems, I will bring out my hidden assumption explicitly, and say under what criteria it does or does not hold; so at least I cannot be accused of subtlety. Since I do not feel that I have yet made the case for a purely outcome-oriented definition of time-invariance, I will not further press the case against causal decision theory in this section.

I do feel I have fairly made my case that Newcomb's Problem and Solomon's Problem have different structures. This structural difference is evidenced by the different *precommitments* which evidential theory and causal theory *agree* would dominate in Newcomb's Problem and Solomon's Problem respectively.

Nozick (1969) begins by presenting Newcomb's Problem as a conflict between the principle of maximizing expected utility and the principle of dominance. Shortly afterward, Nozick introduces the distinction between probabilistic independence and causal independence, suggesting that the dominance principle should apply only when states are causally independent of actions. In effect this reframed Newcomb's Problem as a conflict between the principle of maximizing evidential expected utility and the principle of maximizing causal expected utility, a line of attack which dominated nearly all later discussion.

I think there are many people - especially, people who have not previously been inculcated in formal decision theory - who would say that the most appealing decision is to take only box B in Newcomb's Problem, *and* to eat vanilla ice cream in Newcomb's Soda.

After writing the previous sentence, I posed these two dilemmas to four friends of mine who had not already heard of Newcomb's Problem. (Unfortunately most of my friends have already heard of Newcomb's Problem, and hence are no longer "naive reasoners" for the purpose of psychological experiments.) I told each friend that the Predictor had been observed to correctly predict the decision of 90% of one-boxers and also 90% of two-boxers. For the second dilemma I specified that 90% of people who ate vanilla ice cream did in fact drink the Vanilla Soda and likewise with chocolate eaters and Chocolate Soda. Thus the internal payoffs and probabilities were symmetrical between Newcomb's Problem and Newcomb's Soda. One of my friends was a two-boxer; and of course he also ate vanilla ice cream in Newcomb's Soda. My other three friends answered that they would one-box on Newcomb's Problem. I then posed Newcomb's Soda. Two friends answered immediately that they would eat the vanilla ice cream; one friend said chocolate, but then said, wait, let me reconsider, and answered vanilla. Two friends felt that their answers of "Only box B" and "vanilla ice cream"

were perfectly consistent; my third friend felt that these answers were inconsistent in some way, but said that he would stick by them regardless.

This is a small sample size. But it does confirm to some degree that some naive humans who one-box on Newcomb's Problem would also eat vanilla ice cream in Newcomb's Soda.

Traditionally people who give the "evidential answer" to Newcomb's Problem and the "causal answer" to Solomon's Problem are regarded as vaccillating between evidential decision theory and causal decision theory. The more so, as Newcomb's Problem and Solomon's Problem have been considered identically structured - in which case any perceived difference between them would stem from psychological framing effects. Thus, I introduced the idea of precommitment to show that Newcomb's Problem and Solomon's Problem are *not* identically structured. Thus, I introduced the idea of dynamic consistency to show that my friends who chose one box and ate vanilla ice cream gave *interesting* responses - responses with the admirable harmony that my friends would precommit to the same actions they would choose in-the-moment.

There is a potential logical flaw in the very first paper ever published on Newcomb's Problem, in Nozick's assumption that evidential decision theory has *anything whatsoever* to do with a one-box response. It is the retroductive fallacy: "All evidential agents choose only one box; the human Bob chooses only one box; therefore the human Bob is an evidential agent." When we test evidential decision theory as a *psychological hypothesis* for a *human decision algorithm*, observation frequently contradicts the hypothesis. It is not uncommon - my own small experience suggests it is the *usual* case - to find someone who one-boxes on Newcomb's Problem yet endorses the "causal" decision in variants of Solomon's Problem. So evidential decision theory, considered as an algorithmic hypothesis, explains the psychological phenomenon (Newcomb's Problem) which it was first invented to describe; but evidential decision theory does not successfully predict other psychological phenomena (Solomon's Problem). We should readily abandon the evidential theory in favor of an alternative psychological hypothesis, if a better hypothesis presents itself - a hypothesis that predicts a broader range of phenomena or has simpler mechanics.

What sort of hypothesis would explain people who choose one box in Newcomb's Problem and who send for another's spouse, smoke, or chew gum in Solomon's Problem? Nozick (1993) proposed that humans use a weighted mix of causal utilities and evidential utilities. Nozick suggested that people one-box in Newcomb's Problem because the *differential* evidential expected utility of one-boxing is overwhelmingly high, compared to the differential causal expected utilities. On the evidential view a million dollars is at stake; on the causal view a mere thousand dollars is at stake. On any weighting that takes both evidential utility and causal utility noticeably into account, the evidential differentials in Newcomb's Problem will swamp the causal differentials. Thus Nozick's

psychological hypothesis retrodicts the observation that many people choose only one box in Newcomb's Problem; yet send for another's spouse, smoke, or chew gum in Solomon's Problem. In Solomon's Problem as usually presented, the evidential utility does not completely swamp the causal utility.

Ledwig (2000) complains that formal decision theories which select only one box in Newcomb's Problem are rare (in fact, Ledwig says that the evidential decision theory of Jeffrey (1965) is the only such theory he knows); and goes on to sigh that "Argumentative only-1-box-solutions (without providing a rational decision theory) for Nozick's original version of Newcomb's problem are presented over and over again, though." Ledwig's stance seems to be that although taking only one box is very appealing to naive reasoners, it is difficult to justify it within a rational decision theory.

I reply that it is wise to value winning over the possession of a rational decision theory, just as it is wise to value truth over adherence to a particular mode of reasoning. An expected utility maximizer should maximize utility - not formality, reasonableness, or defensibility.

Of course I am not without sympathy to Ledwig's complaint. Indeed, the point of this paper is to present a systematic decision procedure which ends up maximally rewarded when challenged by Newcomblike problems. It is surely better to have a rational decision theory than to not have one. All else being equal, the more formalizable our procedures, the better. An algorithm reduced to mathematical clarity is likely to shed more light on underlying principles than a verbal prescription. But it is not the goal in Newcomb's Problem to be reasonable or formal, but to walk off with the maximum sum of money. Just as the goal of science is to uncover truth, not to be scientific. People succeeded in transitioning from Aristotelian authority to science at least partially because they could appreciate the value of truth, apart from valuing authoritarianism or scientism.

It is surely the job of decision theorists to systematize and formalize the principles involved in deciding rationally; but we should not lose sight of which decision results in attaining the ends that we desire. If one's daily work consists of arguing for and against the reasonableness of decision algorithms, one may develop a different apprehension of reasonableness than if one's daily work consisted of confronting real-world Newcomblike problems, watching naive reasoners walk off with all the money while you struggle to survive on a grad student's salary. But it is the latter situation that we are actually trying to prescribe - not, how to win arguments about Newcomblike problems, but how to maximize utility on Newcomblike problems.

Can Nozick's mixture hypothesis explain people who say that you should take only box B, and also eat vanilla ice cream in Newcomb's Soda? No: Newcomb's Soda is a precise inverse of Newcomb's Problem, including the million dollars at

stake according to evidential decision theory, and the mere thousand dollars at stake according to causal decision theory. It is apparent that my friends who would take only box B in Newcomb's Problem, and who also wished to eat vanilla ice cream with Newcomb's Soda, *completely ignored* the prescription of evidential theory. For evidential theory would advise them that they must eat chocolate ice cream, on pain of losing a million dollars. Again, my friends were naive reasoners with respect to Newcomblike problems.

If Newcomb's Problem and Newcomb's Soda expose a *coherent* decision principle that leads to choosing only B *and* choosing vanilla ice cream, then it is clear that this coherent principle may be brought into conflict with either evidential expected utility (Newcomb's Soda) or causal expected utility (Newcomb's Problem). That the principle is *coherent* is a controversial suggestion - why should we believe that mere naive reasoners are coherent, when humans are so frequently inconsistent on problems like the Allais Paradox? As suggestive evidence I observe that my naive friends' observed choices have the intriguing property of being consistent with the preferred precommitment. My friends' past and future selves may not be set to war one against the other, nor may precommitment costs be swindled from them. This harmony is absent from the evidential decision principle and the causal decision principle. Should we not give naive reasoners the benefit of the doubt, that they may think more coherently than has heretofore been appreciated? Sometimes the common-sense answer is wrong and naive reasoning goes astray; aye, that is a lesson of science; but it is also a lesson that sometimes common sense turns out to be right.

If so, then perhaps Newcomb's Problem brings causal expected utility into conflict with this third principle, and *therefore* is used by one-boxers to argue against the prudence of causal decision theory. Similarly, Solomon's Problem brings into conflict evidential expected utility on the one hand, and the third principle on the other hand, and *therefore* Solomon's Problem appears as an argument against evidential decision theory.

Considering the blood, sweat and ink poured into framing Newcomb's Problem as a conflict between evidential expected utility and causal expected utility, it is no trivial task to reconsider the entire problem. Along with the evidential-versus-causal debate there are certain methods, rules of argument, that have become implicitly accepted in the field of decision theory. I wish to present not just an alternate answer to Newcomb's Problem, or even a new formal decision theory, but also to introduce different ways of thinking about dilemmas.

5: Invariance and reflective consistency.

In the previous section, I defined *time-invariance* of a dilemma as requiring the invariance of agents' outcomes given a fixed decision and different times at which the decision was made. In the field of physics, the *invariances* of a problem are important, and physicists are trained to notice them. Physicists

consider the law known as *conservation of energy* a consequence of the fact that the laws of physics do not vary with time. Or to be precise, that the laws of physics are invariant under translation in time. Or to be even more precise, that all equations relating physical variables take on the same form when we apply the coordinate transform $t' = t + x$ where x is a constant.

Physical equations are invariant under coordinate transforms that describe *rotation in space,* which corresponds to the principle of conservation of angular momentum. Maxwell's Equations are invariant (the measured speed of light is the same) when time and space coordinates transform in a fashion that we now call the theory of Special Relativity. For more on importance physicists attach to invariance under transforming coordinates, see e.g. Chapter 17 of the Feynman Lectures on Physics, Vol III. *Invariance is interesting;* that is one of the ways that physicists have learned to think.

I want to make a very loose analogy here to decision theory, and offer the idea that there are decision principles which correspond to certain kinds of invariance in dilemmas. For example, there is a correspondence between *time-invariance* in a dilemma, and *dynamic consistency* in decision-making. If a dilemma is *not* time-invariant, so that it makes a difference *when* you make your decision to perform a fixed action at a fixed time, then we have no right to criticize agents who pay precommitment costs, or enforce mental resolutions against their own anticipated future preferences.

The hidden question - the subtle assumption - is how to determine whether it makes a "difference" at what time you decide. For example, an evidential decision theorist might say that two decisions are *different* precisely in the case that they bear different news-values, in which case Newcomb's Soda is not time-invariant because deciding on the same action at different times carries different news-values. Or a causal decision theorist might say that two decisions are *different* precisely in the case that they bear different causal relations, in which case Newcomb's Problem is not time-invariant because deciding on the same action at different times carries different causal relations.

In the previous section I declared that my own criterion for time-invariance was identity of outcome. If agents who decide at different times experience different outcomes, then agents who pay an extra precommitment cost to decide early may do reliably better than agents who make the same decision in-the-moment. Conversely, if agents who decide at different times experience the same outcome, then you cannot do reliably better by paying a precommitment cost.

How to choose which criterion of *difference* should determine our criterion of *invariance?*

To move closer to the heart of this issue, I wish to generalize the notion of *dynamic consistency* to the notion of *reflective consistency.* A decision algorithm

is *reflectively inconsistent* whenever an agent using that algorithm wishes she possessed a different decision algorithm. Imagine that a decision agent possesses the ability to choose among decision algorithms - perhaps she is a self-modifying Artificial Intelligence with the ability to rewrite her source code, or more mundanely a human pondering different philosophies of decision.

If a self-modifying Artificial Intelligence, who implements some particular decision algorithm, ponders her anticipated future and rewrites herself because she would rather have a different decision algorithm, then her old algorithm was *reflectively inconsistent.* Her old decision algorithm was unstable; it defined desirability and expectation such that an alternate decision algorithm appeared more desirable, not just under its own rules, but under her current rules.

I have never seen a formal framework for computing the relative expected utility of different *abstract* decision algorithms, and until someone invents such, arguments about *reflective inconsistency* will remain less formal than analyses of dynamic inconsistency. One may formally illustrate reflective inconsistency only for specific concrete problems, where we can directly compute the alternate prescriptions and alternate consequences of different algorithms. It is clear nonetheless that reflective inconsistency generalizes dynamic inconsistency: All dynamically inconsistent agents are reflectively inconsistent, because they wish their future algorithm was such as to make a different decision.

What if an agent is not self-modifying? Any case of *wistful regret* that one does not implement an alternative decision algorithm similarly shows reflective inconsistency. A two-boxer who, contemplating Newcomb's Problem in advance, *wistfully regrets* not being a single-boxer, is reflectively inconsistent.

I hold that under certain circumstances, agents may be reflectively inconsistent *without* that implying their prior irrationality. Suppose that you are a self-modifying expected utility maximizer, and the parent of a three-year-old daughter. You face a superintelligent entity who sets before you two boxes, A and B. Box A contains a thousand dollars and box B contains two thousand dollars. The superintelligence delivers to you this edict: Either choose between the two boxes *according to the criterion of choosing the option that comes first in alphabetical order,* or the superintelligence will kill your three-year-old daughter.

You cannot win on this problem by choosing box A *because* you believe this choice saves your daughter and maximizes expected utility. The superintelligence has the capability to monitor your thoughts - not just predict them but monitor them directly - and will kill your daughter unless you implement a particular kind of decision *algorithm* in coming to your choice, irrespective of any actual choice you make. A human, in this scenario, might well be out of luck. We cannot stop ourselves from considering the consequences of our actions; it is what we are.

But suppose you are a self-modifying agent, such as an Artificial Intelligence with full access to her own source code. If you attach a sufficiently high utility to your daughter's life, you can save her by executing a simple modification to your decision algorithm. The source code for the old algorithm might be described in English as "Choose the action whose anticipated consequences have maximal expected utility." The new algorithm's source code might read "Choose the action whose anticipated consequences have maximal expected utility, *unless* between 7AM and 8AM on July 3rd, 2109 A.D., I am faced with a choice between two labeled boxes, in which case, choose the box that comes alphabetically first without calculating the anticipated consequences of this decision." When the new decision algorithm executes, the superintelligence observes that you have chosen box A according to an alphabetical decision algorithm, and therefore does not kill your daughter. We will presume that the superintelligence does consider this satisfactory; and that choosing the alphabetically first action by executing code which calculates the expected utility of this action's probable consequences and compares it to the expected utility of other actions, would not placate the superintelligence.

So in *this particular dilemma* of the Alphabetical Box*,* we have a scenario where a self-modifying decision agent would rather alphabetize than maximize expected utility. We can postulate a nicer version of the dilemma, in which opaque box A contains a million dollars if and only if the Predictor believes you will choose your box by alphabetizing. On this dilemma, agents who alphabetize do systematically better - experience reliably better outcomes - than agents who maximize expected utility.

But I do not think this dilemma of the Alphabetical Box shows that choosing the alphabetically first decision is more rational than maximizing expected utility. I do not think this dilemma shows a defect in rationality's prescription to predict the consequences of alternative decisions, *even though* this prescription is reflectively inconsistent given the dilemma of the Alphabetical Box. The dilemma's mechanism invokes a superintelligence who shows prejudice in favor of a particular decision *algorithm,* in the course of purporting to demonstrate that agents who implement this algorithm do systematically better.

Therefore I cannot say: If there exists *any* dilemma that would render an agent reflectively inconsistent, that agent is irrational. The criterion is definitely too broad. Perhaps a superintelligence says: "Change your algorithm to alphabetization or I'll wipe out your entire species." An expected utility maximizer may deem it rational to self-modify her algorithm under such circumstances, but this does not reflect poorly on the original algorithm of expected utility maximization. Indeed, I would look unfavorably on the rationality of any decision algorithm that did *not* execute a self-modifying action, in such desperate circumstance.

To make *reflective inconsistency* an interesting criterion of irrationality, we have to *restrict* the range of dilemmas considered fair. I will say that I consider a dilemma "fair", if when an agent underperforms other agents on the dilemma, I consider this to speak poorly of that agent's rationality. To strengthen the judgment of irrationality, I require that the "irrational" agent should *systematically* underperform other agents in the long run, rather than losing once by luck. (*Someone* wins the lottery every week, and his decision to buy a lottery ticket was irrational, whereas the decision of a rationalist not to buy the same lottery ticket was rational. Let the lucky winner spend as much money as he wants on more lottery tickets; the more he spends, the more surely he will see a net loss on his investment.) I further strengthen the judgment of irrationality by requiring that the "irrational" agent *anticipate* underperforming other agents; that is, her underperformance is not due to unforeseen catastrophe. (Aaron McBride: "When you know better, and you still make the mistake, that's when ignorance becomes stupidity.")

But this criterion of *de facto* underperformance is still not sufficient to reflective inconsistency. For example, all of these requirements are satisfied for a causal agent in Solomon's Problem. In the chewing-gum throat-abscess problem, people who are CGTA-negative tend to avoid gum and also have much lower throat-abscess rates. A CGTA-positive causal agent may chew gum, systematically underperform CGTA-negative gum-avoiders in the long run, and even *anticipate* underperforming gum-avoiders, but none of this reflects poorly on the agent's rationality. A CGTA-negative agent will do better than a CGTA-positive agent regardless of what either agent decides; the background of the problem treats them differently. Nor is the CGTA-positive agent who chews gum reflectively inconsistent - she may wish she had different genes, but she doesn't wish she had a different decision *algorithm*.

With this concession in mind - that observed underperformance does not always imply reflective inconsistency, and that reflective inconsistency does not always show irrationality - I hope causal decision theorists will concede that, as a matter of straightforward fact, causal decision agents are reflectively inconsistent on Newcomb's Problem. A causal agent that expects to face a Newcomb's Problem in the near future, whose current decision algorithm reads "Choose the action whose anticipated causal consequences have maximal expected utility", and who considers the two actions "Leave my decision algorithm as is" or "Execute a self-modifying rewrite to the decision algorithm 'Choose the action whose anticipated causal consequences have maximal expected utility, unless faced with Newcomb's Problem, in which case choose only box B'", will evaluate the rewrite as having more desirable (causal) consequences. Switching to the new algorithm in *advance* of actually confronting Newcomb's Problem, directly causes box B to contain a million dollars and a payoff of $1,000,000; whereas the action of keeping the old algorithm directly causes box B to be empty and a payoff of $1,000.

Causal decision theorists may dispute that Newcomb's Problem reveals a dynamic inconsistency in causal decision theory. There is no actual preference reversal between two outcomes or two gambles. But reflective inconsistency generalizes dynamic inconsistency. All dynamically inconsistent agents are reflectively inconsistent, but the converse does not apply - for example, being confronted with an Alphabetical Box problem does not render you *dynamically* inconsistent. It should not be in doubt that Newcomb's Problem renders a causal decision algorithm reflectively inconsistent. On Newcomb's Problem a causal agent systematically underperforms single-boxing agents; the causal agent anticipates this in advance; and a causal agent would prefer to self-modify to a different decision algorithm.

But does a causal agent *necessarily* prefer to self-modify? Isaac Asimov once said of Newcomb's Problem that he would choose only box A. Perhaps a causal decision agent is proud of his rationality, holding clear thought sacred. Above all other considerations! Such an agent will contemptuously refuse the Predictor's bribe, showing not even wistful regret. No amount of money can convince this agent to behave as if his button-press controlled the contents of box B, when the plain fact of the matter is that box B is already filled or already empty. Even if the agent could self-modify to single-box on Newcomb's Problem in advance of the Predictor's move, the agent would refuse to do so. The agent attaches such high utility to a *particular mode of thinking,* apart from the actual consequences of such thinking, that no possible bribe can make up for the disutility of departing from treasured rationality. So the agent is reflectively consistent, but only trivially so, i.e., because of an immense, explicit utility attached to implementing a particular decision *algorithm*, apart from the decisions produced or their consequences.

On the other hand, suppose that a causal decision agent has no attachment whatsoever to a particular mode of thinking - the causal decision agent cares *nothing whatsoever* for rationality. Rather than love of clear thought, the agent is driven solely by greed; the agent computes *only* the expected monetary reward in Newcomblike problems. (Or if you demand a psychologically realistic dilemma, let box B possibly contain a cure for your daughter's cancer – just to be sure that the outcome matters more to you than the process.) If a causal agent first considers Newcomb's Problem while staring at box B which is already full or empty, the causal agent will compute that taking both boxes maximizes expected utility. But if a causal agent considers Newcomb's Problem *in advance* and assigns significant probability to encountering a future instance of Newcomb's Problem, the causal agent will prefer, to an unmodified algorithm, an algorithm that is otherwise the same except for choosing only box B. I do not say that the causal agent *will* choose to self-modify to the 'patched' algorithm - the agent might prefer some third algorithm to *both* the current algorithm and the patched algorithm. But if a decision agent, facing some dilemma, prefers *any* algorithm to her current algorithm, that dilemma renders the agent reflectively inconsistent.

The question then becomes whether the causal agent's reflective inconsistency reflects a dilemma, Newcomb's Problem, which is just as unfair as the Alphabetical Box.

The idea that Newcomb's Problem is *unfair* to causal decision theorists is not my own invention. From Gibbard and Harper (1978):

> U-maximization [causal decision theory] prescribes taking both boxes. To some people, this prescription seems irrational. One possible argument against it takes roughly the form "If you're so smart, why ain't you rich?" V-maximizers [evidential agents] tend to leave the experiment millionaires whereas U-maximizers [causal agents] do not. Both very much want to be millionaires, and the V-maximizers usually succeed; hence it must be the V-maximizers who are making the rational choice. We take the moral of the paradox to be something else: if someone is very good at predicting behavior and rewards predicted irrationality richly, then irrationality will be richly rewarded.

The argument here seems to be that causal decision theorists are rational, but systematically underperform on Newcomb's Problem because the Predictor despises rationalists. Let's flesh out this argument. Suppose there exists some decision theory Q, whose agents decide in such fashion that they choose to take only one box in Newcomb's Problem. The Q-theorists inquire of the causal decision theorist: "If causal decision theory is rational, why do Q-agents do systematically better than causal agents on Newcomb's Problem?" The causal decision theorist replies: "The Predictor you postulate has decided to punish rational agents, and there is nothing I can do about that. I can just as easily postulate a Predictor who decides to punish Q-agents, in which case you would do worse than I."

I can indeed imagine a scenario in which a Predictor decides to punish Q-agents. Suppose that at 7AM, the Predictor inspects Quenya's state and determines whether or not Quenya is a Q-agent. The Predictor is filled with a burning, fiery hatred for Q-agents; so if Quenya is a Q-agent, the Predictor leaves box B empty. Otherwise the Predictor fills box B with a million dollars. In this situation it is better to be a causal decision theorist, or an evidential decision theorist, than a Q-agent. And in this situation, all agents take both boxes because there is no particular reason to leave behind box A. The outcome is completely independent of the agent's decision - causally independent, probabilistically independent, just plain independent.

We can postulate Predictors that punish causal decision agents regardless of their decisions, or Predictors that punish Q-agents regardless of their decisions. We excuse the resulting underperformance by saying that the Predictor is moved internally by a particular hatred for these kinds of agents. But suppose the Predictor is, internally, utterly indifferent to what sort of mind you are and which

algorithm you use to arrive at your decision. The Predictor cares as little for rationality, as does a greedy agent who desires only gold. Internally, the Predictor cares *only* about your decision, and judges you only according to the Predictor's reliable prediction of your decision. Whether you arrive at your decision by maximizing expected utility, or by choosing the first decision in alphabetical order, the Predictor's treatment of you is the same. Then an agent who takes only box B *for whatever reason* ends up with the best available outcome, while the causal decision agent goes on pleading that the Predictor is filled with a special hatred for rationalists.

Perhaps a decision agent who always chose the first decision in alphabetical order (given some fixed algorithm for describing options in English sentences) would plead that Nature hates rationalists because in most real-life problems the best decision is not the first decision in alphabetical order. But alphabetizing agents do well only on problems that have been carefully designed to favor alphabetizing agents. An expected utility maximizer can succeed even on problems designed for the convenience of alphabetizers, if the expected utility maximizer knows enough to calculate that the alphabetically first decision has maximum expected utility, *and if the problem structure is such that all agents who make the same decision receive the same payoff regardless of which algorithm produced the decision.*

This last requirement is the critical one; I will call it *decision-determination*. Since a problem strictly determined by agent decisions has no remaining room for sensitivity to differences of algorithm, I will also say that the dilemma has the property of being *algorithm-invariant.* (Though to be truly precise we should say: algorithm-invariant given a fixed decision.)

Nearly all dilemmas discussed in the literature are algorithm-invariant. Algorithm-invariance is implied by very act of setting down a payoff matrix whose row keys are decisions, not algorithms. What outrage would result, if a respected decision theorist proposed as proof of the rationality of Q-theory: "Suppose that in problem X, we have an algorithm-indexed payoff matrix in which Q-theorists receive $1,000,000 payoffs, while causal decision theorists receive $1,000 payoffs. Since Q-agents outperform causal agents on this problem, this shows that Q-theory is more rational." No, we ask that "rational" agents be clever - that they exert intelligence to sort out the differential consequences of decisions - that they are not paid just for showing up. Even if an agent is not intelligent, we expect that the alphabetizing agent, who happens to take the rational action because it came alphabetically first, is rewarded *no more and no less* than an expected utility maximizer on that single[9] decision problem.

To underline the point: we are humans. Given a chance, we humans will turn principles or intuitions into timeless calves, and we will imagine that there is a

[9] In the long run the alphabetizing agent would be wise to choose some other philosophy. Unfortunately, there is no decision theory that comes before "alphabetical"; the alphabetizer is consistent under reflection.

magical principle that makes our particular mode of cognition intrinsically "rational" or good. But the idea in decision theory is to move beyond this sort of social cognition by modeling the expected consequences of various actions, and choosing the actions whose consequences we find most appealing (regardless of whether the *type of thinking that can get us these appealing consequences* "feels rational", or matches our particular intuitions or idols.).

Suppose that we observe some class of problem - whether a challenge from Nature or a challenge from multi-player games - and some agents receive systematically higher payoffs than other agents. This payoff difference may not reflect superior *decision-making* capability by the better-performing agents. We find in the gum-chewing variant of Solomon's Problem that agents who avoid gum do systematically better than agents who chew gum, but the performance difference stems from a favor shown these agents by the background problem. We cannot say that *all agents whose decision algorithms produce a given output, regardless of the algorithm, do equally well* on Solomon's Problem.

Newcomb's Problem as originally presented by Nozick is actually *not* decision-determined. Nozick (1969) specified in footnote 1 that if the Predictor predicts you will decide by flipping a coin, the Predictor leaves box B empty. Therefore Nozick's Predictor cares about the algorithm used to produce the decision, and not merely the decision itself. An agent who chooses only B by flipping a coin does worse than an agent who chooses only B by ratiocination. Let us assume unless otherwise specified that the Predictor *predicts equally reliably* regardless of agent algorithm. Either you do not have a coin in your pocket, or the Predictor has a sophisticated physical model which reliably predicts your coinflips.

Newcomb's Problem seems a forcible argument against causal decision theory because of the *decision-determination* of Newcomb's Problem. It is not just that some agents receive systematically higher payoffs than causal agents, but that *any* agent whose decision theory advocates taking only box B will do systematically better, *regardless of how she thought about the problem.* Similarly, any agent whose decision theory advocates taking both boxes will do as poorly as the causal agent, regardless of clever justifications. This state of affairs is known to the causal agent in advance, yet this does not change the causal agent's strategy.

From *Foundations of Causal Decision Theory* (Joyce 1999):

> Rachel has a perfectly good answer to the "Why ain't you rich?" question. "I am not rich," she will say, "because I am not the kind of person the psychologist thinks will refuse the money. I'm just not like you, Irene. Given that I know that I am the type who takes the money, and given that the psychologist knows that I am this type, it was reasonable of me to think that the $1,000,000 was not in my account. The $1,000 was the

most I was going to get no matter what I did. So the only reasonable thing for me to do was to take it."

Irene may want to press the point here by asking, "But don't you wish you were like me, Rachel? Don't you wish that you were the refusing type?" There is a tendency to think that Rachel, a committed causal decision theorist, must answer this question in the negative, which seems obviously wrong (given that being like Irene would have made her rich). This is not the case. Rachel can and should admit that she *does* wish she were more like Irene. "It would have been better for me," she might concede, "had I been the refusing type." At this point Irene will exclaim, "You've admitted it! It wasn't so smart to take the money after all." Unfortunately for Irene, her conclusion does not follow from Rachel's premise. Rachel will patiently explain that wishing to be a refuser in a Newcomb problem is not inconsistent with thinking that one should take the $1,000 *whatever type one is.* When Rachel wishes she was Irene's type she is wishing *for Irene's options,* not sanctioning her choice.

Rachel does not wistfully wish to have a different *algorithm* per se, nor a different genetic background. Rachel wishes, in the most general possible sense, that she were *the type of person who would take only box B.* The specific reasons behind the wistful decision are not given, only the decision itself. No other property of the wistfully desired 'type' is specified, nor is it relevant. Rachel wistfully wishes *only* that she were a member of the entire class of agents who single-box on Newcomb's Problem.

Rachel is reflectively inconsistent on a decision-determined problem - that is agreed by all parties concerned. But for some reason Joyce does not think this is a problem. Is there any way to translate Joyce's defense into the new terminology I have introduced? If a decision-determined problem is not "fair" to a causal decision theorist, what sort of dilemma *is* fair?

Imagine two vaccines A, B which may make a person sick for a day, a week, or a month. Suppose that, as a matter of historical fact, we observe that nearly all agents choose vaccine A, and all agents who choose A are sick for a week; a few agents choose B, and all agents who choose B are sick for a month. Does this matter of historical record prove that the problem is decision-determined and that the agents who choose A are making the rational decision? No. Suppose there are two genotypes, G_A and G_B. All agents of type G_A, if they choose vaccine A, are sick for a week; and if they choose vaccine B they are sick for a month. All agents of type G_B, if they choose vaccine A, are sick for a week; and if they choose vaccine B they are sick for a day. It just so happens that, among all the agents who have ever tried vaccine B, all of them happened to be of genotype G_A. If nobody knows about this startling coincidence, then I do not think anyone is being stupid in avoiding vaccine B. But suppose all the facts *are* known - the agents know their own genotypes and they know that the

consequences are different for different genotypes. Then agents of genotype G_B are foolish to choose vaccine A, and agents of genotype G_A act rationally in choosing vaccine A, even though they make identical decisions and receive identical payoffs. So merely observing the history of a dilemma, and seeing that all agents who did in fact make the same decision did in fact receive the same payoffs, does not suffice to make that problem decision-determined.

How can we provide a stronger criterion of decision-determination? I would strengthen the criterion by requiring that a "decision-determined" dilemma have a *decision-determined mechanism.* That is, there exists some method for computing the outcome that accrues to each particular agent. This computation constitutes the specification of the dilemma, in fact. As decision theorists communicate their ideas with each other, they communicate mechanisms. As agents arrive at beliefs about the nature of the problem they face, they hypothesize mechanisms. The dilemma's mechanism may invoke outside variables, store values in them (reflecting changes to the state of the world), invoke random numbers (flip coins), all on the way to computing the final payoff - the agent's experienced outcome.

The constraint of decision-determination is this: At each step of the mechanism you describe, you cannot refer to any property of an agent except the *decision-type* - what sort of choice the agent makes on decision D, where D is a decision that the agent faces in the past or future of the dilemma. Newcomb's Problem has a decision-determined mechanism. The mechanism of Newcomb's Problem invokes the agent's decision-type twice, once at 7AM when we specify that the Predictor puts a million dollars in box B if the agent is the sort of person who will only take one box, and again at 8AM, when we ask the agent's decision-type in order to determine which boxes the agent actually takes.[10]

At no point in specifying the mechanism of Newcomb's Problem do we need to reference the agent's genotype, algorithm, name, age, sex, or anything else except the agent's *decision-type.*

[10] In some analyses, an agent's action is treated as a separate proposition from the agent's decision - i.e., we find ourselves analyzing the outcome for an agent who *decides* to take only box B but who then *acts* by taking both boxes. I make no such distinction. I am minded of a rabbi I once knew, who turned a corner at a red light by driving through a gas station. The rabbi said that this was legally and ethically acceptable, so long as when he first turned into the gas station he *intended* to buy gas, and then he changed his mind and kept driving. We shall assume the Predictor is not fooled by such sophistries. By "decision-type" I refer to the sort of actual action you end up taking, being the person that you are - not to any interim resolutions you may make, or pretend to make, along the way. If there is some brain-seizure mechanism that occasionally causes an agent to perform a different act then the one decided, we shall analyze this as a stochastic mechanism from decision (or action) to further effects. We do not suppose any *controllable* split between an agent's decision and an agent's act; anything you control is a decision. A causal agent, analyzing the expected utility of different actions, would also need to take into account potential brain-seizures in planning. "Decision" and "action" refer to identical decision-tree branch points, occurring *prior* to any brain seizures. Without loss of generality, we may refer to the agent's decision-type to determine the agent's action.

This constraint is both stronger and weaker than requiring that all agents who took the same actions got the same payoffs in the dilemma's observed history. In the previous dilemma of vaccines, the mechanism made explicit mention of the genotypes of agents in computing the consequences that accrue to those agents, but the mechanism was implausibly balanced, and some agents implausibly foolish, in such way that all agents who happened to make the same decision happened to experience the same outcome. On the other hand, we can specify a mechanism in which the Predictor places a million dollars in box B with 90% probability if the agent is the type of person who will choose only box B. Now not all agents who make the same decision receive the same payoff in observed history - but the mechanism is still strictly decision-determined.

What class of dilemmas does a causal decision theorist deem "fair"? Causal agents excel on the class of *action-determined* dilemmas - dilemmas whose mechanism makes no mention of any property of the agent, except an action the agent has already actually taken. This criterion makes Newcomb's Problem unfair because Newcomb's Problem is not action-determined - Newcomb's Problem makes reference to the decision-type, what sort of decisions the agent *will* make, not strictly those decisions the agent has *already* made.

Action-determined dilemmas, like decision-determined dilemmas, are necessarily algorithm-invariant. If any step of the mechanism is sensitive to an agent's algorithm, then the mechanism is sensitive to something that is not the agent's actual past action. So if causal agents excel on action-determined dilemmas, it's not because those dilemmas explicitly favor causal agents. And there is something fair-sounding, a scent of justice, about holding an agent accountable only for actions the agent *actually has performed,* not actions someone else *thinks* the agent will perform.

But decision-determination is not so broad a criterion of judgment as it may initially sound. My definition specifies that the only decisions whose 'types' are referenceable are decisions that the agent does definitely face at some point in the dilemma's future or past. A decision-determined dilemma uses no *additional information about the agent*, relative to an action-determined dilemma. Either way, the agent makes the same number of choices and those choices strictly determine the outcome. We can translate any action-determined mechanism into a decision-determined mechanism, but not vice versa. Any reference to an agent's actual action in decision D translates into "The type of choice the agent makes in decision D".

I propose that *causal decision theory corresponds to the class of action-determined dilemmas.* On action-determined dilemmas, where every effect of being "the sort of person who makes decision D" follows the actual performance of the action, causal decision theory returns the maximizing answer. On action-determined dilemmas, causal agents exhibit no dynamic inconsistency, no willingness to pay precommitment costs, and no negative information values.

There is no type of agent and no algorithm that can outperform a causal agent on an action-determined dilemma. On action-determined dilemmas, causal agents are reflectively consistent.

Action-determined dilemmas are the lock into which causal decision theory fits as key: there is a direct correspondence between the allowable causal influences in an action-determined mechanism, and the allowable mental influences on decision in a causal agent. In Newcomb's Problem, the step wherein at 7AM the Predictor takes into account the agent's decision-type is a forbidden causal influence in an action-determined dilemma, and correspondingly a causal agent is forbidden to represent that influence in his decision. An agent whose mental representations correspond to the class of action-determined dilemmas, can only treat the Predictor's reliance on decision-type as reliance on a fixed background property of an agent, analogous to a genetic property. Joyce's description of Irene and Rachel is consistent with this viewpoint. Rachel envies only Irene's options, the way a CGTA-positive agent might envy the CGTA-negative agent's options.

A causal agent systematically calculates and chooses the optimal action on action-determined problems. On decision-determined problems which are not also action-determined, the optimal *action* may not be the optimal *decision.* Suppose an agent Gloria, who systematically calculates and chooses the optimal *decision* on all decision-determined problems. By hypothesis in a decision-determined problem, there exists some mapping from decision-types to outcomes, or from decision-types to stochastic outcomes (lotteries), and this mapping is the same for all agents. We allow both stochastic and deterministic mechanisms in the dilemma specification, but the mechanism may rely only on the agent's decision-type and on no other property of the agent; this is the definition of a decision-determined problem. Compounded deterministic mechanisms map decision-types to outcomes. Compounded stochastic mechanisms map decision-types to stochastic outcomes - probability distributions over outcomes; lotteries. We may directly take the utility of a deterministic outcome; we may calculate the expected utility of a stochastic outcome. Thus in a decision-determined problem there exists a mapping from decision-types onto expected utilities, given a utility function.

Suppose Gloria has true knowledge of the agent-universal fixed mapping from decision-types onto stochastic outcomes. Then Gloria can map stochastic outcomes onto expected utilities, and select a decision-type such that no other decision-type maps to greater expected utility; then take the corresponding decision at every juncture. Gloria, as constructed, is optimal on decision-determined problems. Gloria always behaves in such a way that she has the decision-type she wishes she had. No other agent or algorithm can systematically outperform Gloria on a decision-determined problem; on such problems Gloria is dynamically consistent and reflectively consistent. Gloria corresponds to the class of decision-determined problems the way a causal

agent corresponds to the class of action-determined problems. Is Gloria *rational?* Regardless my point is that we can in fact construct Gloria. Let us take Gloria as specified and analyze her.

6: Maximizing decision-determined problems

Let Gloria be an agent who, having true knowledge of any decision-determined problem, calculates the invariant mapping between agent decision-types and (stochastic) outcomes, and chooses a decision whose type receives a maximal expected payoff (according to Gloria's utility function over outcomes). The method that Gloria uses to break ties is unimportant; let her alphabetize.

Gloria reasons as follows on Newcomb's Problem: "An agent whose decision-type is 'take two boxes' receives $1,000 [with probability 90%, and $1,001,000 with probability 10%]. An agent whose decision-type is 'take only B' receives $1,000,000 [with probability 90%, and $0 with probability 10%]. I will therefore be an agent of the type who takes only B." Gloria then does take only box B.

Gloria only carries out the course of action to which causal agents would like to precommit themselves. If Gloria faces a causal agent with the power of precommitment and both consider Newcomb's Problem in advance, Gloria can do no better than the causal agent. Gloria's distinctive capability is that she can compute her decisions on-the-fly. Gloria has no need of precommitment, and therefore, no need of *advance* information. Gloria can systematically outperform resolute causal agents whenever agents are not told which exact Newcomb's Problem they will face, until *after* the Predictor has already made its move. According to a causal decision agent who suddenly finds himself in the midst of a Newcomb's Problem, it is already too late for anything he does to affect the contents of box B; there is no point in precommitting to take only box B *after* box B is already full or empty. Gloria reasons in such fashion that the Predictor correctly concludes that when Gloria suddenly finds herself in the midst of a Newcomb's Problem, Gloria will reason in such fashion as to take only box B. Thus when Gloria confronts box B, it is already full. By Gloria's nature, she always *already* has the decision-type causal agents wish they had, without need of precommitment.

The causal agent Randy, watching Gloria make her decision, may call out to her: "Don't do it, Gloria! Take both boxes; you'll be a thousand dollars richer!" When Gloria takes only box B, Randy may be puzzled and dismayed, asking: "What's wrong with you? Don't you believe that if you'd taken both boxes, you would have received $1,001,000 instead of $1,000,000?" Randy may conclude that Gloria believes, wrongly and irrationally, that her action physically affects box B in some way. But this is anthropomorphism, or if you like, causalagentomorphism. A causal agent will single-box only if the causal agent believes this action physically causes box B to be full. If a causal agent stood in Gloria's shoes and single-boxed, it would follow from his action that he believed his action had a direct effect on box B. Gloria, as we have constructed her, need not work this

way; no such thought need cross her mind. Gloria constructs the invariant map from decision-types to outcomes, then (predictably) makes the decision corresponding to the decision-type whose associated outcome she assigns the greatest expected utility. (From the Predictor's perspective, Gloria already has, has always had, this decision-type.) We can even suppose that Gloria is a short computer program, fed a specification of a decision-determined problem in a tractably small XML file, so that we *know* Gloria isn't thinking the way a causal agent would need to think in her shoes in order to choose only box B.

If we imagine Gloria to be possessed of a humanlike psychology, then she might equally ask the causal agent, choosing both boxes: "Wait! Don't you realize that your decision-type had an influence on whether box B was full or empty?" The causal agent, puzzled, replies: "What difference does that make?" Gloria says, "Well... don't you need to believe that whether you're the sort of person who single-boxes or two-boxes had no influence on box B, in order to believe that the sort of agents who two-box receive higher expected payoffs than the sort of agents who single-box?" The causal agent, now *really* confused, says: "But what does that have to do with anything?" And Gloria replies: "Why, that's the whole criterion by which I make decisions!"

Again, at this point I have made no claim that Gloria is rational. I have only claimed that, granted the notion of a decision-determined problem, we can *construct* Gloria, and she matches or systematically outperforms every other agent on the class of decision-determined problems, which includes most Newcomblike problems and Newcomb's Problem itself.

How can we explain the fact that Gloria outperforms causal agents on problems which are decision-determined but not action-determined? I would point to a *symmetry,* in Gloria's case, between the facts that determine her decision, and the facts that her decision-type determines. Gloria's decision-type influences whether box B is empty or full, as is the case for all agents in Newcomb's Problem. Symmetrically, Gloria knows that her decision-type influences box B, and this knowledge influences her decision and hence her decision-type. Gloria's decision-type, viewed as a timeless fact about her, is influenced by everything which Gloria's decision-type influences. Because of this, when we plug Gloria into a decision-determined problem, she receives a maximal payoff.

The same symmetry holds for a causal agent on action-determined problems, which is why a causal agent matches or outperforms all other agents on an action-determined problem. On an action-determined problem, every outcome influenced by a causal agent's action may influence the causal agent, at least if the causal agent knows about it.

Suppose that at 7:00:00AM on Monday, causal agent Randy must choose between pressing brown or orange buttons. If the brown button is pressed, it trips a lever which delivers $1,000 to Randy. If the orange button is pressed, it

pops a balloon which releases $10,000 to Randy. Randy can only press one button.

It is impossible for a $10,000 payoff to Randy at 7:00:05AM to influence Randy's choice at 7:00:00AM. The future does not influence the past. This is the confusion of "final causes" which misled Aristotle. But Randy's *belief* that the orange button drops $10,000 into his lap, can be considered as a physical cause - a physically real pattern of neural firings. And this physical belief is active at 7:00:00AM, capable of influencing Randy's action. If Randy's belief is *accurate,* he closes the loop between the future and the past. The future consequence can be regarded as influencing the present action mediated by Randy's accurate belief.

Now suppose that the orange button, for some odd reason, also causes $1,000,000 dollars *not* to be deposited into Randy's account on Wednesday. (That is, the deposit will happen *unless* the orange button is pressed.) If Randy believes this, then Randy will ordinarily not press the orange button, pressing the brown button instead. But suppose Randy is not aware of this fact. Or, even stranger, suppose that Randy *is* aware of this fact, but for some reason the potential $1,000,000 is simply not allowed to enter into Randy's deliberations. This breaks the symmetry - there is now some *effect* of Randy's action, which is not also a *cause* of Randy's action via Randy's present knowledge of the effect. The *full* effect on Randy will be determined by *all* the effects of Randy's action, whereas Randy determines his action by optimizing over a *subset* of the effects of Randy's action. Since Randy only takes into account the $1,000 and $10,000 effects, Randy chooses in such fashion as to bring about the $10,000 effect by pressing the orange button. Unfortunately this foregoes a $1,000,000 gain. The potential future effects of $1,000,000, $10,000, and $1000 are now determined by the influence of *only* the $10,000 and $1,000 effects on Randy's deliberations. Alas for Randy that his symmetry broke. Now other agents can systematically outperform him.

Gloria, if we presume that she has a sufficiently humanlike psychology, might similarly criticize causal agents on Newcomb's Problem. "The sort of decision an agent makes, being the person that he is" determines the Predictor's prediction and hence the content of box B, yet causal agents do not permit their knowledge of this link to enter into their deliberations, hence it does not influence their decision, hence it does not influence the sort of decision that they make being the people that they are. On a decision-determined problem, Gloria makes sure that every known facet of the dilemma's mechanism which depends on "What sort of decision Gloria makes, being the person that she is", enters into Gloria's deliberations as an influence on her decision - maintaining the symmetric link between outcomes and the determinant of outcomes. Similarly, in an action-determined problem, a causal agent will try to ensure that every belief he has about the effect of his action, enters into his deliberations to influence his action.

Call this *determinative symmetry.* On an X-determined dilemma (e.g. decision-determined, action-determined), determinative symmetry holds when every facet of the problem (which we believe) X determines, helps determine X (in our deliberations).

Let Reena be a resolute causal agent. Suppose Reena is told that she will face a decision-determined Newcomblike Problem, but not what kind of problem, so that Reena cannot precommit to a *specific* choice. Then Reena may make the fully general resolution, "I will do whatever Gloria would do in my shoes on this upcoming problem." But what if Reena anticipates that she might be plunged into the midst of a Newcomblike problem without warning? Reena may resolve, "On *any* problem I ever encounter that is decision-determined but not action-determined, I will do what Gloria would do in my shoes." On action-determined problems, Gloria reduces to Reena. So Reena, making her fully general resolution, transforms herself wholly into Gloria. We might say that Reena *reflectively reduces* to Gloria.

Why does this happen to Reena? In the moment of decision, plunged in the midst of Newcomb's Paradox without the opportunity to make resolutions, Reena reasons that the contents of box B are already fixed, regardless of her action. Looking into the future in advance of the Predictor's move, Reena reasons that any change of algorithm, or resolution which she now makes, will alter not only her decision but her decision-type. If Reena resolves to act on a different criterion in a Newcomblike problem, Reena *sees* this as not only affecting her action in-the-moment, but also as affecting "the sort of decision I make, being the person that I am" which plays a role in Newcomblike problems. For example, if Reena considers irrevocably resolving to take only box B, in advance, Reena expects this to have two effects: (a) future-Reena will take only box B (b) the Predictor will predict that future-Reena will take only box B.

When Reena considers the future effect of resolving irrevocably or changing her own decision algorithm, Reena sees this choice as affecting both her action and her decision-type. Thus Reena sees her resolution or self-modification as having causal consequences for all variables which a decision-type determines. Reena looking into her *future* takes into account precisely the same considerations as does Gloria in her *present*. Reena is determinatively symmetric when she sees the problem ahead of time. Thus Reena, choosing between *algorithms* in *advance*, reflectively reduces to Gloria.

In section 5 I said:

> An evidential decision theorist might say that two decisions are *different* precisely in the case that they bear different news-values, in which case Newcomb's Soda is not time-invariant because deciding on the same action at different times carries different news-values. Or a causal decision theorist might say that two decisions are *different* precisely in the

> case that they bear different causal relations, in which case Newcomb's Problem is not time-invariant because deciding on the same action at different times carries different causal relations.
>
> In the previous section I declared that my own criterion for time-invariance was identity of outcome. If agents who decide at different times experience different outcomes, then agents who pay an extra precommitment cost to decide early may do reliably better than agents who make the same decision in-the-moment. Conversely, if agents who decide at different times experience the same outcome, then you cannot do reliably better by paying a precommitment cost.
>
> How to choose which criterion of *difference* should determine our criterion of *invariance?* To move closer to the heart of this issue, I wish to generalize the notion of *dynamic consistency* to the notion of *reflective consistency...*

It is now possible for me to justify concisely my original definition of time-invariance, which focused only on the *experienced outcomes* for agents who decide a fixed action at different times. A self-modifying agent, looking into the future and choosing between algorithms, and who does not attach any utility to a specific algorithm apart from its consequences, will evaluate two algorithms A and B as equivalent whenever agents with algorithms A or B always receive the same payoffs. Let Elan be an evidential agent. Suppose Elan reflectively evaluates the consequences of self-modifying to algorithms A and B. If algorithms A and B always make the same decisions but decide in different ways at different times (for example, algorithm A is Gloria, and algorithm B is resolute Reena), and the problem is time-invariant as I defined it (invariance of *outcomes only*), then Elan will evaluate A and B as having the same utility. Unless Elan attaches intrinsic utility to possessing a particular algorithm, *apart* from its consequences; but we have said Elan does not do this. It is of no consequence to Elan whether the two decisions, at different times, have different news-values for the future-Elan who makes the decision. To evaluate the expected utility of a self-modification, Elan evaluates utility only over the expected outcomes for future-Elan.

Similarly with causal agent Reena, who attaches no intrinsic utility to causal decision theory *apart from* the outcomes it achieves. Reena, extrapolating forward the effects of adopting a particular algorithm, does not need to notice when algorithm A makes a decision at 7AM that bears a different causal relation (but the same experienced outcome) than algorithm B making the same decision at 8AM. Reena is not evaluating the expected utility of self-modifications over *internal features* of the algorithm, such as whether the algorithm conforms to a particular mode of reasoning. So far as Reena is concerned, if you can do better by alphabetizing, all to the good. Reena starts out as a causal agent, and she will use causal decision theory to extrapolate the future and decide which

considered algorithm has the highest expected utility. But Reena is not *explicitly* prejudiced in favor of causal decision theory; she uses causal decision theory *implicitly* to ask which choice of algorithm leads to which outcome, but she does not *explicitly* compare a considered self-modification against her current algorithm.

The concept of "reflective consistency" forces my particular criterion for time-invariance of a dilemma. Reflective agents who attach no special utility to algorithms *apart from* their expected consequences, considering a time-invariant dilemma, will consider two algorithms as equivalent (because of equivalent expected outcomes), if the only difference between the two algorithms is that they make the same fixed decisions at different times. Therefore, if on a time-invariant dilemma, an agent prefers different decisions about a fixed dilemma at different times, leading to different outcomes with different utilities, *at least one of* those decisions must imply the agent's reflective inconsistency.

Suppose that at 7AM the agent decides to take action A at 9AM, and at 8AM the agent decides to take action B at 9AM, where the experienced outcomes are the same regardless of the decision time, but different for actions A and B, and the different outcomes have different utilities. Now let the agent consider the entire problem in advance at 6AM. Either agents who take action A at 7AM do better than agents who take action B at 8AM, in which case it is an improvement to have an algorithm that replicates the 7AM decision at 8AM; or agents who take action B at 8AM do better than agents who take action A at 7AM, in which case it is better to have an algorithm that replicates the 8AM decision at 7AM.

Let time-invariance be defined only over agents *experiencing the same outcome* regardless of at what different times they decide to perform a fixed action at a fixed time. Then any agent who would prefer different precommitments at different times - without having learned new information, and with different outcomes with different utilities resulting - will be *reflectively inconsistent*. Therefore I suggest that we should call an agent *dynamically inconsistent* if they are reflectively inconsistent, in this way, on a time-invariant problem. If we define time-invariance of a dilemma *not* in terms of experienced outcomes - for example, by specifying that decisions bear the same news-values at different times, or bear the same causal relations at different times - then there would be no link between reflective consistency and dynamic consistency.

I say this not because I am prejudiced *against* news-value or causal linkage as useful elements of a decision theory, but because I am prejudiced *toward* outcomes as the proper final criterion. An evidential agent considers news-value *about outcomes;* a causal agent considers causal relations *with outcomes.* Similarly a reflective agent should relate algorithms to outcomes.

Given that time-invariance is invariance of outcomes, a decision-determined problem is necessarily time-invariant. A dilemma's mechanism citing only "the

sort of decision this agent makes, being the person that she is", makes no mention of *when* the agent comes to that decision. Any such dependency would break the fixed mapping from decision-types to outcomes; there would be a new index key, the time at which the decision occurred.

Since Gloria is reflectively consistent on decision-determined problems, and since dynamically inconsistent agents are reflectively inconsistent on time-invariant problems, it follows that Gloria is dynamically consistent.

7: Is decision-dependency fair?

Let Gloria be an agent who maximizes decision-determined problems. I have offered the following reasons why Gloria is interesting enough to be worthy of further investigation:

On decision-determined problems, and *given full knowledge of the dilemma's mechanism*:

1. Gloria is dynamically consistent. Gloria always makes the same decision to which she would prefer to precommit.
2. Gloria is reflectively consistent. Gloria does not wistfully wish she had a different algorithm.
3. Gloria is determinatively symmetric. Every dependency known to Gloria of the dilemma's mechanism on "What sort of decision Gloria makes, being the person that she is," enters into those deliberations of Gloria's which determine her decision.
4. Gloria matches or systematically outperforms every other kind of agent. Relative to the fixed mapping from decision-types to stochastic outcomes, Gloria always turns out to possess the decision-type with optimal expected utility according to her utility function.
5. If we allege that a causal agent is rational and Gloria is not, then Gloria possesses the interesting property of being the kind of agent that rational agents wish they were, if rational agents expect to encounter decision-determined problems.

Suppose no rational agent ever expects to encounter a non-action-determined decision-determined problem? Then Gloria becomes less interesting. It seems to me that this equates to a *no-box* response to Newcomb's Problem, the argument that Newcomb's Problem is impossible of realization, and hence no problem at all. When was the last time you saw a superintelligent Predictor?

Gloria, as we have defined her, is defined only over completely decision-determined problems of which she has full knowledge. However, the agenda of Part II of this manuscript is to introduce a formal, general decision theory which reduces to Gloria as a special case. That is, on decision-determined problems of which a timeless agent has full knowledge, the timeless agent executes the decision attributed to Gloria. Similarly, TDT reduces to causal decision theory on

action-determined dilemmas. I constructed Gloria to highlight what I perceive as defects in contemporary causal decision theory. Gloria also gives me a way to refer to certain decisions - such as taking only box B in Newcomb's Problem - which most contemporary decision theorists would otherwise dismiss as naive, irrational, and not very interesting. Now I can say of both single-boxing and eating vanilla ice cream that they are "Gloria's decision", that is, the decision which maps to maximum payoff on a decision-determined problem.

But even in the general case, the following categorical objection may be launched against the fairness of any problem that is *not* action-determined:

"The proper use of intelligent decision-making is to evaluate the alternate effects of an action, choose, act, and thereby bring about desirable consequences. To introduce any other effects of the decision-making process, such as Predictors who take different actions conditional upon your predicted decision, is to introduce effects of the decision-making mechanism quite different from its design purpose. It is no different from introducing a Predictor who rewards or punishes you, conditional upon whether you believe the sky is blue or green. The proper purpose of belief is to control our predictions and hence direct our actions. If you were to introduce *direct* effects of belief upon the dilemma mechanism, who knows what warped agents would thrive? Newcomb's Problem is no different; it introduces an extraneous effect of a cognitive process, decision-making, which was originally meant to derive only the best causal consequence of our actions."

The best *intuitive* justification I have heard for taking into account the influence of dispositions on a dilemma, apart from the direct effects of actions, is Parfit (1984)'s dilemma of the hitchhiker:

> "Suppose that I am driving at midnight through some desert. My car breaks down. You are a stranger and the only other driver near. I manage to stop you, and I offer you a great reward if you rescue me. I cannot reward you now, but I promise to do so when we reach my home. Suppose next that I am *transparent,* unable to deceive others. I cannot lie convincingly. Either a blush, or my tone of voice, always gives me away. Suppose, finally, that I know myself to be never self-denying. If you drive me to my home, it would be worse for me if I gave you the promised reward. Since I know that I never do what will be worse for me, I know that I shall break my promise. Given my inability to lie convincingly, you know this too. You do not believe my promise, and therefore leave me stranded in the desert. This happens to me because I am never self-denying. It would have been better for me if I had been *trustworthy,* disposed to keep my promises even when doing so would be worse for me. You would then have rescued me."

Here the conflict between decision-determination and causal decision theory arises simply and naturally. In Parfit's Hitchhiker there is none of the artificiality

that marks the original Newcomb's Problem. Other agents exist in our world; they will naturally try to predict our future behaviors; and they will treat us differently conditionally upon our predicted future behavior. Suppose that the potential rescuer, whom I will call the Driver, is a selfish amoralist of the sort that often turns up in decision problems. When the Driver reasons, "I will leave this person in the desert unless I expect him to pay me $100 for rescuing him," the Driver is not expressing a moralistic attitude; the Driver is not saying, "I don't think you're worth rescuing if you're self-interested and untrustworthy." Rather my potential rescuer would need to expend $20 in food and gas to take me from the desert. If I will reward my rescuer with $100 after my rescue, then a selfish rescuer maximizes by rescuing me. If I will not so reward my rescuer, then a selfish rescuer maximizes by leaving me in the desert. If my potential rescuer is a good judge of character, my fate rests entirely on my own dispositions.

We may say of the potential rescuer, in Parfit's Hitchhiker, that he is no Gandhi, to demand reward. But an utterly selfish rescuer can hardly be accused of setting out to reward irrational behavior. My rescuer is not even obliged to regard me as a moral agent; he may regard me as a black box. Black boxes of type B produce $100 when taken from the desert, black boxes of type A produce nothing when taken from the desert, and the rescuer strives to accurately distinguish these two types of boxes. There is no point in picking up a box A; those things are heavy.

The categorical objection to disposition-influenced dilemmas is that they invoke an *arbitrary* extraneous influence of a cognitive mechanism upon the external world. Parfit's Hitchhiker answers this objection by demonstrating that the influence is not *arbitrary;* it is a real-world problem, not a purely hypothetical dilemma. If I interact with other intelligent agents, it naturally arises that they, in the course of maximizing their own aims, treat me in a way contingent upon their predictions of my behavior. To the extent that their predictions are the slightest bit reflective of reality, my disposition does influence the outcome. If I refuse to take into account this influence in determining my decision (hence my disposition), then my determinative symmetry with respect to the problem is broken. I become reflectively inconsistent and dynamically inconsistent, and other agents can systematically outperform me.

It may be further objected that Parfit's Hitchhiker is not realistic because people are not perfectly transparent, as Parfit's dilemma specifies. But it does not require decision-*determination,* or even a *strong* influence, to leave the class of action-determined problems and break the determinative symmetry of causal decision theory. If there is the faintest disposition-influence on the dilemma, then it is no longer *necessarily* the case that causal decision theory returns a reflectively consistent answer.

Remember that action-determined problems are a *special case* of decision-determined problems. There is no obvious *cost* incurred by being determinatively

symmetric with respect to dispositional influences - taking disposition-influenced mechanisms into account doesn't change how you handle problems that lack dispositional influences. CDT prescribes decisions not only for action-determined dilemmas where CDT is reflectively consistent, but also prescribes decisions for decision-determined dilemmas. CDT does not return "Error: Causal decision theory not applicable" when considering Newcomb's Problem, but unhesitatingly prescribes that we should take two boxes. I would say that CDT corresponds to the class of dilemmas in which dispositions have *no* influence on the problem apart from actions. From my perspective, it is unfortunate that CDT makes a general prescription even for dilemmas that CDT is not adapted to handle.

The argument under consideration is that I should adopt a decision theory in which my decision takes general account of dilemmas whose mechanism is influenced by "the sort of decision I make, being the person that I am" and not just the direct causal effects of my action. It should be clear that *any* dispositional influence on the dilemma's mechanism is sufficient to carry the force of this argument. There is no minimum influence, no threshold value. There would be a threshold value if taking account of dispositional influence carried a *cost,* such as suboptimality on other problems. In this case, we would demand a dispositional influence large enough to make up for the incurred cost. (Some philosophers say that if Newcomb's Predictor is *infallible,* then and only then does it become rational to take only box B.) But it seems to me that if the way that other agents treat us exhibits even a 0.0001 dependency on our own dispositions, then causal decision theory returns *quantitatively* a poor answer. Even in cases where the actual decisions correlate with Gloria's, the quantitative calculation of expected utility will be off by a factor of 0.0001 from Gloria's. Some decision problems are continuous - for example, you must choose where to draw a line or how much money to allocate to different strategies. On continuous decision problems, a slight difference in calculated expected utility will produce a slightly different action.

It is not enough to say, "I have never yet encountered a Newcomb's Predictor", or to say, "I am not perfectly transparent to the driver who encounters me in the desert." If the Predictor can do 0.0001 better than chance, then causal decision theory is arguably the wrong way to calculate expected utility. If you are the *slightest bit* transparent, if the faintest blush colors your cheeks; then from a decision-theoretic perspective, the argument against causal decision theory has just as much force qualitatively, though it makes a smaller quantitative difference.

A possible counterargument is to assert the *complete* nonexistence of dispositional influences after other legitimate influences are taken into account. Suppose that Newcomb's Predictor makes its prediction of me by observing my behavior in past Newcomb's Problems; suppose that Parfit's driver decides to pick me up based on my good reputation. In both cases there would exist a significant observed correlation between my present decision, and the move of Newcomb's Predictor or Parfit's driver; nor would this observation reflect an

extraneous genetic factor as of Solomon's Problem, the correlation arises only from the sort of decisions I make, being the person that I am. Nonetheless a causal agent maximizes such a problem. It is quite legitimate, under causal decision theory, to say: "I will behave in a trustworthy fashion on this occasion, thereby effecting that in future occasions people will trust me." In the dilemma of Parfit's Hitchhiker, if we propose that a causal agent behaves untrustworthily and fails, it would seem to follow that the causal agent anticipates that his reputation has no effect on future dilemmas. Is this realistic?

A causal agent may take only box B on a single Newcomb's Problem, if the causal agent anticipates thereby influencing the Predictor's move in future Newcomb's Problems. That is a direct causal effect of the agent's action. Note, mind you, that the causal agent is *not* reasoning: "It is rational for me to take only box B on round 1 of Newcomb's Problem because I thereby increase the probability that *I* will take only box B on round 2 of Newcomb's Problem." And the causal agent is *certainly* not reasoning, "How wonderful that I have an excuse to take only box B! Now I will get a million dollars on this round." Rather the causal agent reasons, "I will take only box B on round 1 of Newcomb's Problem, deliberately forgoing a $1,000 gain, because this increases the probability that the Predictor will put $1,000,000 in box B on round 2 of Newcomb's Problem."

For this reasoning to carry through, the increase in expected value of the future Newcomb's Problems must exceed $1,000, the value given up by the causal agent in refusing box A. Suppose there is no observed dependency of the Predictor's predictions on past actions? Instead we observe that the Predictor has a 90% chance of predicting successfully a person who chooses two boxes, and a 90% chance of predicting successfully a person who chooses only box B, *regardless of past history.* If someone chooses only box B for five successive rounds, and then on the sixth round chooses both boxes, then based on the Predictor's observed record, we would predict a 90% probability, in advance of opening box B, that box B will be found to be empty. And this prediction would be just the same, regardless of the past history of the agent. If an agent chooses only box B on the first five rounds, *we* may expect the agent to choose only box B on the sixth round and therefore expect that box B has already been filled by $1,000,000. But once we observe that the agent actually *does* choose both boxes in the sixth round, this *screens off* the agent's earlier actions from our prediction of B's contents. However the Predictor predicts, it isn't based on reputation.

If this condition holds, then even in the iterated Newcomb's Problem, the causal agent has no excuse to take only box B. The causal agent's action on the first round does not influence the Predictor's prediction on the second round.

A further difficulty arises if the Newcomb's Problem is not iterated indefinitely. If the Newcomb's Problem lasts five rounds, then the causal agent may hope to single-box on the first four rounds, thereby tricking the Predictor into filling box B

on the fifth round. But the causal agent will take both boxes on the fifth round because there is no further iteration of the problem and no reason to forgo a $1,000 gain now that box B is already filled. The causal agent knows this; it is obvious. Can we suppose the Predictor does not know it too? So the Predictor will empty box B on the fifth round. Therefore the causal agent, knowing this, has no reason to single-box on the fourth round. But the Predictor can reason the same way also. And so on until we come to the conclusion that there is no rational reason to single-box on the first round of a fivefold-iterated Newcomb's Problem.

Suppose the exact number of iterations is not known in advance? Say our uncertain knowledge is that Newcomb's Problem may be iterated dozens, thousands, or millions of times. But suppose it is common knowledge that Newcomb's Problem will definitely *not* exceed a googolplex iterations. Then if the dilemma does somehow reach the $10^{10^{100}}$ th round, it is obvious to all that the agent will take both boxes. Therefore the agent has no motive to take only box B if the dilemma reaches Round $10^{10^{100}}$ -1. And so on until we reason, with the expenditure of some reams of paper, to Round 1.

In the reasoning above, on the final round of a fivefold iteration, the Predictor does not predict the agent's action in the fifth round strictly by induction on the agent's action in the past four rounds, but by anticipating an obvious thought of the causal decision agent. That is why it is *possible* for me to depict the causal agent as failing. On a *strictly* action-determined problem the causal agent *must* win. But conversely, for causal decision theory to give qualitatively and quantitatively the right answer, others' treatment of us must be *strictly* determined by reputation, *strictly* determined by past actions. If Parfit's Driver encounters me in the desert, he may look up my reputation on Google, without that violating the preconditions for applying causal decision theory. But what if there is the faintest blush on my cheeks, the tiniest stutter in my voice?

What if my body language casts the smallest subconscious influence on the Driver's decision? Then the expected utility will come out differently. Even for a causal agent it will come out differently, if the causal agent ponders in advance the value of precommitment. We could eliminate the influence of dispositions by supposing that I have total control of my body language, so that I can control every factor the Driver takes into account. But of course, if I have total control of my body language, a wise Driver will not take my body language into much account; and in any event human beings do *not* have perfect control of voice and body language. We are not perfectly transparent. But we are not perfectly opaque, either. We betray to some greater or lesser degree the decisions we know we will make. For specifics, consult e.g. Ekman (2004).

Parfit's Hitchhiker is not a purely decision-determined problem. Perhaps some people, depending on how they reason, blush more readily than others; or perhaps some people believe themselves to be trustworthy but are mistaken.

These are mechanisms in the dilemma that are not *strictly* decision-determined; the mechanisms exhibit dependency on algorithms and even dependency on belief. Gloria, confronting Parfit's dilemma, shrugs and says "Not applicable" unless the driver is an ideal Newcomblike Predictor. Perhaps confronting Parfit's dilemma you would wish to possess an algorithm such that you would believe falsely that you will reward the driver, and then fail to reward him. (Of course if humans ran such algorithms, or could adopt them, then a wise Driver would ignore your beliefs about your future actions, and seek other ways to predict you.) But in real human life, where we cannot *perfectly* control our body language, nor *perfectly* deceive ourselves about our own future actions, Parfit's dilemma is not strictly action-determined. Parfit's dilemma considered as a *real-life* problem exhibits, if not strict decision-determination, then at least decision-*contamination.*

Newcomb's Problem is not commonly encountered in everyday life. But it is realistic to suppose that the driver in a real-life Parfit's Hitchhiker may have a *non-zero* ability to guess our trustworthiness. I like to imagine that the driver is Paul Ekman, who has spent decades studying human facial expressions and learning to read tiny twitches of obscure facial muscles. Decision theories should not break down when confronted by Paul Ekman; he is a real person. Other humans also have a *non-zero* ability to guess, in advance, our future actions.

Modeling agents as influenced *to some greater or lesser degree* by "the sort of decision you make, being the person that you are", *realistically describes present-day human existence.*

A purely hypothetical philosophical dilemma, you may label as unfair. But what is the use of objecting that real life is unfair? You may object if you wish.

To be precise - to make only statements whose meaning I have clearly defined - I cannot say that I have shown causal decision theory to be "irrational", or that Gloria is "more rational" than a causal decision theorist on decision-determined problems. I can make statements such as "Causal decision theory is reflectively inconsistent on a class of problems which includes real-world problems" or "A causal decision theorist confronting a decision-determined problem wistfully wishes he were Gloria."

I can even say that *if* you are presently a causal decision theorist, and *if* you attach no especial intrinsic utility to conforming to causal decision theory, and *if* you expect to encounter a problem in real life that is decision-contaminated, *then* you will wish to adopt an alternative decision procedure that exhibits determinative symmetry - a procedure that takes into account each anticipated effect of your disposition, in your decision which determines your disposition. But if you attach an especial intrinsic utility to conforming to causal decision theory, you might not so choose; you would be trivially consistent under reflection.

Of course such statements are hardly irrelevant to the rationality of the decision; but the relevance is, at least temporarily, left to the judgment of the reader. Whoever wishes to dispute my mistaken statement that agent G is reflectively inconsistent in context C, will have a much easier time of it than someone who sets out to dispute my mistaken claim that agent G is irrational.

8: Renormalization

Gibbard and Harper (1978) offer this variation of Newcomb's Problem:

> The subject of the experiment is to take the contents of the opaque box first and learn what it is; he then may choose either to take the thousand dollars in the second box or not to take it. The Predictor has an excellent record and a thoroughly accepted theory to back it up. Most people find nothing in the first box and then take the contents of the second box. Of the million subjects tested, one per cent have found a million dollars in the first box, and strangely enough only one per cent of these - one hundred in ten thousand - have gone on to take the thousand dollars they could each see in the second box. When those who leave the thousand dollars are later asked why they did so, they say things like "If I were the sort of person who would take the thousand dollars in that situation, I wouldn't be a millionaire."
>
> On both grounds of U-maximization [causal decision theory] and of V-maximization [evidential decision theory], these new millionaires have acted irrationally in failing to take the extra thousand dollars. They know for certain that they have the million dollars; therefore the V-utility of taking the thousand as well is 101, whereas the V-utility of not taking it is 100. Even on the view of V-maximizers, then, this experiment will almost always make irrational people and only irrational people millionaires. Everyone knows so at the outset.
>
> ...why then does it seem obvious to many people that [in Newcomb's original problem] it is rational to take only the opaque box and irrational to take both boxes? We have three possible explanations... The second possible explanation lies in the force of the argument "If you're so smart, why ain't you rich?" That argument, though, if it holds good, should apply equally well to the modified Newcomb situation... There the conclusion of the argument seems absurd: according to the argument, having already received the million dollars, one should pass up the additional thousand dollars one is free to take, on the grounds that those who are disposed to pass it up tend to become millionaires. *Since the argument leads to an absurd conclusion in one case, there must be something wrong with it.* [italics added]

Call this the Transparent Newcomb's Problem. By now you can see that the "absurd conclusion" is not so readily dismissed. Neither an evidential decision

theorist, nor a causal decision theorist, would pass up the extra thousand dollars. But any resolute agent would resolve to pass up the thousand. Any self-modifying agent would modify to an algorithm that passed up the thousand. Any reflectively consistent decision theory would necessarily pass up the thousand.

It seems to me that arguing from the *intuitive, psychological, seeming folly* of a particular decision in a particular dilemma, has often served decision theory ill. It is a common form of argument, of which this manuscript is hardly free! But the force of Gibbard and Harper's argument comes not from an *outcome* (the agents who take only box B become millionaires) but from a *seeming absurdity* of the decision itself, considered purely as reasoning. If we argue from the seeming folly of a decision, *apart* from the systematic underperformance of agents who make that decision, we end up judging a new algorithm by its exact dilemma-by-dilemma *conformance* to our current theory, rather than asking which *outcomes* accrue to which algorithms.

Under the criterion of reflective consistency, checking the *moment-by-moment* conformance of a new theory to your current theory, has the same result as attaching an especial intrinsic utility to a particular ritual of cognition. Someone says: "Well, I'm not going to adopt decision theory Q because Q would advise me to pass up the thousand dollars in the Transparent Newcomb's Problem, and this decision is *obviously absurd*." Whence comes the negative utility of this absurdity, the revulsion of this result? It's not from the experienced outcome to the agent - an agent who bears such an algorithm gets rich. Rather, Gibbard and Harper attach disutility to a decision algorithm because its prescribed decision appears absurd under the logic of their current decision theory. The principle of reflective consistency stipulates that you use your current model of reality to check the *outcomes* predicted for agents who have different decision *algorithms* - not that you should imagine yourself in the shoes of agents as they make their momentary decisions, and consider the apparent "absurdity" or "rationality" of the momentary decisions under your current theory. If I evaluate new algorithms only by comparing their momentary decisions to those of my current theory, I can never change theories! By fiat my current theory has been defined as the standard of perfection to which all new theories must aspire; why would I ever adopt a new theory? I would be reflectively consistent but trivially so, like an agent that attaches a huge intrinsic utility (larger than the payoff in any imaginable problem) to keeping his current algorithm.

Human beings are not just philosophers considering decision theories; we also *embody* decision theories. Decision is not a purely theoretical matter to us. Human beings have chosen between actions for millennia before the invention of decision theory as philosophy, let alone decision theory as mathematics. We don't just ponder decision algorithms as intangible abstractions. We *embody* decision algorithms; our thoughts move in patterns of prediction and choice; that is much of our existence as human beings. We know what it feels like to *be* a decision theory, from the inside.

Gibbard and Harper say, "On both grounds of U-maximization and of V-maximization, these new millionaires have acted irrationally" in passing up the thousand dollars. In so doing, Gibbard and Harper evaluate the millionaire's decision under the momentary logic of two deliberately considered, abstract, mathematical decision theories: maximization of causal expected utility and maximization of evidential expected utility. That is, Gibbard and Harper compare the millionaire's decision to two *explicit* decision theories. But this argument would not sound convincing (to Gibbard and Harper) if passing up the thousand dollars *felt* right to them. Gibbard and Harper also say, "The conclusion of the argument seems absurd... since the argument leads to an absurd conclusion in one case, there must be something wrong with it." When Gibbard and Harper use the word *absurd,* they talk about how the decision feels from the inside of the decision algorithm they currently *embody* - their intuitive, built-in picture of how to make choices. Saying that U-maximization does not endorse a decision, is an explicit comparison to an explicit theory of U-maximization. Saying that a decision *feels absurd,* is an implicit comparison to the decision algorithm that you yourself embody. "I would never do *that,* being the person that I am" - so you think to yourself, embodying the decision algorithm that you do.

Arguing from the seeming *absurdity* of decisions is dangerous because it assumes we implicitly embody a decision algorithm which is already optimal, and the only task is systematizing this implicit algorithm into an explicit theory. What if our embodied decision algorithm is not optimal? Natural selection constructed the human brain. Natural selection is not infallible, not even close. Whatever decision algorithms a naive human being embodies, exist because those algorithms worked most of the time in the ancestral environment. For more on the fallibility of evolved psychology, see Tooby and Cosmides (1992).

But what higher criterion could we possibly use to judge harshly our own decision algorithms? The first thing I want to point out is that we *do* criticize our own decision-making mechanisms. When people encounter the Allais Paradox, they sometimes (though not always) think better of their preferences, for B over A or C over D. If you read books of cognitive psychology, especially the heuristics-and-biases program, you will become aware that human beings tend to overestimate small probabilities; fall prey to the conjunction fallacy; judge probability by representativeness; judge probability by availability; display a status quo bias because of loss aversion and framing effects; honor sunk costs. In all these cases you may (or may not) then say, "How silly! From now on I will try to avoid falling prey to these biases." How is it possible that you should say such a thing? How can you possibly judge harshly your own decision algorithm? The answer is that, despite the incredulous question, there is no paradox involved - there is no reason why our mechanisms of thought should *not* take themselves as their own subject matter. When the implicit pattern of a cognitive bias is made clear to us, explicitly described as an experimental result in psychology, we look at this

cognitive bias and say, "That doesn't look like a way of thinking that would be effective for achieving my goals, therefore it is not a good idea."

We use our implicit decision algorithms to choose between explicit decision theories, judging them according to how well they promise to achieve our goals. In this way a flawed algorithm may repair itself, providing that it contains sufficient unflawed material to carry out the repair. In politics we expect the PR flacks of a political candidate to defend his every action, even those that are indefensible. But a decision algorithm does not need to behave like a political candidate; there is no requirement that a decision theory have a privileged tendency to self-protect or self-justify. There is no law which states that a decision algorithm must, in every case of deciding between *algorithms*, prefer the algorithm that best agrees with its momentary decisions. This would amount to a theorem that *every* decision algorithm is *always* consistent under reflection.

As humans we are fortunate to be blessed with an inconsistent, ad-hoc system of compelling intuitions; we are lucky that our intuitions may readily be brought into conflict. Such a system is undoubtedly flawed under its own standards. But the richness, the redundancy of evolved biology, is cause for hope. We can criticize intuitions with intuitions and so renormalize the whole.

What we *are,* implicitly, at the object level, does not always seem to us as a good idea, when we consider it explicitly, at the meta-level. If in the Allais Paradox my object-level code makes me prefer B over A and separately makes me prefer C over D, it doesn't mean that when the Allais Paradox is explained to me *explicitly* I will value the intuition responsible. The heuristic-and-bias responsible for the Allais Paradox (subjective overweighting of small probabilities) is not invoked when I ponder the abstract question of whether to adopt an explicit theory of expected utility maximization. The mechanism of my mind is such that the object-level error does not directly protect itself on the reflective level.

A human may understand complicated things that do not appear in the ancestral environment, like car engines and computer programs. The human ability to comprehend abstractly also extends to forces that appear in the ancestral environment but were not ancestrally understood, such as nuclear physics and natural selection. And our ability extends to comprehending ourselves, not concretely by placing ourselves in our own shoes, but abstractly by considering regularities in human behavior that experimental psychologists reveal. When we consider ourselves abstractly, and ask after the desirability of the cognitive mechanisms thus revealed, we are under no obligation to regard our current algorithms as optimal.

Not only is it *possible* for you to use your current intuitions and philosophical beliefs to choose between proposed decision theories, you *will* do so. I am not presuming to command you, only stating what seems to me a fact. Whatever criterion you use to accept or reject a new decision theory, the cognitive

operations will be carried out by your current brain. You can no more decide by a criterion you have not yet adopted than you can lift yourself up by your own bootstraps.

Imagine an agent Abby whose brain contains a bug that causes her to choose the first option in alphabetical order whenever she encounters a decision dilemma that involves choosing between exactly four options. For example, Abby might encounter a choice between these four lotteries: "Fifty percent chance of winning $1000," "Ninety percent chance of winning $10,000", "Ten percent chance of winning $10", and "Eight percent chance of winning $100." Abby chooses the 8% chance of winning $100 because "eight" comes first in alphabetical order. We should imagine that this choice *feels* sensible to Abby, indeed, it is the only choice that feels sensible. To choose a 90% chance of winning $10,000, in this dilemma, is clearly absurd. We can even suppose that Abby has systematized the rule as an appealing explicit principle: "When there are exactly four options, choose the first option in alphabetical order." This is the principle of alphabetical dominance, though it only holds when there are exactly four options - as one can readily verify by imagining oneself in the shoes of someone faced with such a dilemma. As an explanation, this explicit principle fully accounts for the observed pattern of sensibility and absurdity in imagined choices.

However, Abby soon notices that the principle of alphabetical dominance can readily be brought into conflict with other principles that seem equally appealing. For example, if in a set of choices **D** we prefer the choice A, and we also prefer A to B, then we should prefer A in the set {B} U **D**. More generally, Abby decides, an agent should never do worse as a result of choices being *added* - of more options becoming available. In an intuitive sense (thinks Abby) greater freedom of choice should always make an agent *more* effective, if the agent chooses wisely. For the agent always has it within her power *not* to perform any hurtful choice. What agent that makes wise use of her power could be hurt by an offer of greater freedom, greater power? Agents that do strictly worse with a strictly expanded set of choices must behave pathologically in some way or other. Yet *adding* the option "Ten percent chance of winning $10" to the set "Fifty percent chance of winning $1000", "Ninety percent chance of winning $10,000", and "Eight percent chance of winning $100", will on the average make Abby around $9,000 poorer. In this way Abby comes to realize that her intuitions are not consistent with her principles, nor her principles consistent with each other.

Abby's "buggy" intuition - that is, the part of Abby's decision algorithm that *we* would regard as insensible - is a special case. It is not active under all circumstances, only in those circumstances where Abby chooses between exactly four options. Thus, when Abby considers the outcome to an agent who possesses some algorithm that chooses a 90% chance at $10,000, versus the outcome for her current algorithm, Abby will conclude that the former outcome is

better and that bearing the former algorithm yields higher expected utility for an agent faced with such a dilemma.

In this way, Abby can repair herself. She is not so broken (from our outside perspective) that she is incapable even of seeing her own flaw. Of course, Abby might end up concluding that while it is *better* to be an agent who takes the 90% chance at $10,000, this does not imply that the choice is *rational* - to her it still feels absurd. If so, then from our outside perspective, Abby has seen the light but not absorbed the light into herself; she has mastered her reasons but not her intuitions.

Intuitions are not sovereign. Intuitions can be improved upon, through training and reflection. Our visuospatial intuitions, evolved to deal with the task of hunting prey and dodging predators on the ancestral savanna, use algorithms that treat space as flat. On the ancestral savanna (or in a modern-day office) the curvature of space is so unnoticeable that much simpler cognitive algorithms for processing flat space give an organism virtually all of the benefit; on the savanna there would be no evolutionary advantage to a cognitive system that correctly represented General Relativity. As a result of this evolutionary design shortcut, Immanuel Kant would later declare that space by its very nature was flat, and that though the contradiction of Euclid's axioms might be consistent they would never be comprehensible. Nonetheless physics students master General Relativity. I would also say that a *wise* physics student does not say, "How strange is physics, that space is curved!" but rather "How strange is the human parietal cortex, that we think space is flat!"

A universally alphabetical agent might prefer "alphabetical decision theory" to "causal decision theory" and "evidential decision theory", since "alphabetical" comes alphabetically first. This agent is broken beyond repair. How can we resolve our dispute with this agent over what is "rational"? I would reply by saying that the word "rational" is being used in a conflated and confusing sense. Just because this agent bears an algorithm that outputs the first action in alphabetical order, and I output an action whose consequences I anticipate to be best, does not mean that we disagree over what is wise, or right, or rational in the way of decision. It means I am faced with a process so foreign that it is useless to regard our different behaviors as imperfect approximations of a common target. Abby is close enough to my way of thinking that I can argue with her about decision theory, and perhaps convince her to switch to the way that I think is right. An alphabetical agent is an utterly foreign system; it begs the question to call it an "agent". None of the statements that I usually regard as "arguments" can affect the alphabetical agent; it is outside my frame of reference. There is not even the core idea of a cognitive relation between selection of decisions and consequences of decisions.

Perhaps I could suggest to the alphabetical agent that it consider switching to "Abby's decision theory". Once adopted, Abby's decision theory can repair itself

further. I would not regard the first step in this chain as an "argument", but rather as reprogramming a strange computer system so that for the first time it implements a fellow agent. The steps *after* that are arguments.

We should not too early conclude that a fellow agent (let alone a fellow human being) is beyond saving. Suppose that you ask Abby which decision algorithm seems to her wisest, on Abby's dilemma of the four options, and Abby responds that self-modifying to an algorithm which chooses an 8% chance at $100 seems to her the best decision. Huh? you think to yourself, and then realize that Abby must have considered four algorithms, and "An algorithm that chooses an eight percent chance at $100" came first alphabetically. In this case, the original flaw (from our perspective) in Abby's decision theory has reproduced itself under reflection. But that doesn't mean Abby is beyond saving, or that she is trapped in a self-justifying loop immune to argument. You could try to ask Abby which algorithm she prefers if she must choose only between the algorithm she has now, and an algorithm that is the same but for deleting Abby's principle of alphabetical dominance. Or you could present Abby with many specific algorithms, making the initial dilemma of four options into a choice between five or more algorithms for treating those four options.

You could also try to brute-force Abby into what you conceive to be sanity, asking Abby to choose between four hypothetical options: "Instantly destroy the whole human species", "Receive $100", "Receive $1000", and "Solve all major problems of the human species so that everyone lives happily ever after." Perhaps Abby, pondering this problem, would reluctantly say that she thought the *rational* action was to instantly destroy the whole human species in accordance with the principle of alphabetic dominance, but in this case she would be strongly tempted to do something irrational.

Similarly, imagine a Newcomb's Problem in which a black hole is hurtling toward Earth, to wipe out you and everything you love. Box B is either empty or contains a black hole deflection device. Box A as ever transparently contains $1000. Are you tempted to do something irrational? Are you tempted to change algorithms so that you are no longer a causal decision agent, saying, perhaps, that though you treasure your rationality, you treasure Earth's life more? If so, then you *never were* a causal decision agent deep down, whatever philosophy you adopted. The Predictor has already made its move and left. According to causal decision theory, it is too late to change algorithms - though if you do decide to change your algorithm, the Predictor has undoubtedly taken that into account, and box B was always full from the beginning.

Why should the magnitude of the stakes make a difference? One might object that in such a terrible dilemma, the value of a thousand dollars vanishes utterly, so that in taking box A there is no utility at all. Then let box A contain a black-hole-deflector that has a 5% probability of working, and let box B either be empty or contain a deflector with a 99% probability of working. A 5% chance of saving

the world may be a small probability, but it is an *inconceivably* huge expected utility. Still it is better for us by far if box B is full rather than empty. Are you tempted yet to do something irrational? What *should* a person do, in that situation? Indeed, now that the Predictor has come and gone, what do you *want* that agent to do, who confronts this problem on behalf of you and all humanity?

If raising the stakes this high makes a psychological difference to you - if you are tempted to change your answer in one direction or another - it is probably because raising the stakes to Earth increases attention paid *to the stakes* and decreases the attention paid to prior notions of rationality. Perhaps the rational decision is precisely that decision you make when you care more about the stakes than being "rational".

Let us suppose that the one who faces this dilemma on behalf of the human species is causal to the core; he announces his intention to take both boxes. A watching single-boxer pleads (in horrible fear and desperation) that it would be better to have an algorithm that took only box B. The causal agent says, "It would have been better to me to adopt such an algorithm in advance; but now it is too late for changing my algorithm to change anything." The single-boxer hopelessly cries: "It is only your *belief* that it is too late that *makes* it too late! If you believed you could control the outcome, you could!" And the causal agent says, "Yes, I agree that if I now believed falsely that I could change the outcome, box B would always have been full. But I do not believe falsely, and so box B has always been empty." The single-boxer says in a voice sad and mournful: "But do you not see that it would be better for Earth if you were the sort of agent who would switch algorithms in the moment whenever it would be wise to switch algorithms in advance?" "Aye," says the causal agent, his voice now also sad. "Alas for humanity that I did not consider the problem in advance!"

The agent could decide, even at this late hour, to use a determinatively symmetric algorithm, so that his decision is determined by all those factors which are affected by "the sort of decision he makes, being the person that he is." In which case the Predictor has already predicted that outcome and box B already contains a black-hole-deflector. The causal agent has no trouble seeing the value to humanity had he switched algorithms in *advance;* but after the Predictor leaves, the argument seems moot. The causal agent can even see in *advance* that it is better to be the sort of agent who switches algorithms when confronted with the decision in the moment, but in the moment, it seems absurd to change to the sort of agent who switches algorithms in the moment.

From the perspective of a single-boxer, the causal agent has a blind spot concerning actions that are taken after the Predictor has already made its move - analogously to our perspective on Abby's blind spot concerning sets of four options. Abby may even reproduce (what we regard as) her error under reflection, if she considers four alternative algorithms. To show Abby her blind spot, we can present her with two algorithms as options, or we can present her

with five or more algorithms as options. Perhaps Abby wonders at the conflict of her intuitions, and says: "Maybe I should consider four algorithms under reflection, rather than considering two algorithms or five algorithms under reflection?" If so, we can appeal to meta-reflection, saying, "It would be better for you to have a reflective algorithm that considers two algorithms under reflection than to have a reflective algorithm that considers four algorithms under reflection." Since this dilemma compares two alternatives, it should carry through to the decision we regard as sane.

Similarly, if the single-boxer wishes to save the world by showing the causal agent what the single-boxer sees as his blind spot, she can ask the causal agent to consider the problem before the Predictor makes Its move. Unfortunately the single-boxer does have to get to the causal agent before the Predictor does. After the Predictor makes Its move, the causal agent's "blind spot" reproduces itself reflectively; the causal agent thinks it is too late to change algorithms. The blind spot even applies to meta-reflection. The causal agent can see that it would have been best to have adopted in advance a reflective algorithm that would think it was not too late to change algorithms, but the causal agent thinks it is now too late to adopt such a reflective algorithm.

But the single-boxer's plight is only truly hopeless if the causal agent is "causal to the core" - a formal system, perhaps. If the causal agent is blessed with *conflicting* intuitions, then the watching single-boxer can hope to save the world (for by *her* lights it is not yet too late) by strengthening one-box intuitions. For example, she could appeal to plausible general principles of pragmatic rationality, such as that a prudent agent should not do worse as the result of having greater freedom of action - should not pay to have fewer options. This principle applies equally to Abby who anticipates doing worse when we increase her free options to four, and to a causal agent who anticipates doing better when the free option "take both boxes" is not available to him.

If the agent faced with the Newcomb's Problem on humanity's behalf is *truly* causal to the core, like a formal system, then he will choose both boxes with a song in his heart. Even if box A contains only ten dollars, and box B possibly contains a black-hole-deflector, an agent that is causal to the core will choose both boxes - scarcely perturbed, amused perhaps, by the single-boxer's horrified indignation. The agent who is causal to the core does not even think it worth his time to discuss the problem at length. For nothing much depends on his choice between both box A and B versus only box B - just ten dollars.

So is the causal agent "rational"? Horrified as we might be to learn the news of his decision, there is still something appealing about the principle that we should not behave as if we control what we cannot affect. Box B *is* already filled or empty, after all.

9: Creating space for a new decision theory.

If a tree falls in the forest, and no one hears it, does it make a sound? The falling tree *does* cause vibrations in the air, waves carrying acoustic energy. The acoustic energy *does not* strike a human eardrum and translate into auditory experiences. Having said this, we have fully described the event of the falling tree and can answer any testable question about the forest that could hinge on the presence or absence of "sound". We can say that a seismographic needle will vibrate. We can say that a device which (somehow) audits human neurons and lights on finding the characteristic pattern of auditory experiences, will not light. What more is there to say? What testable question hinges on whether the falling tree makes a sound? Suppose we know that a computer program is being demonstrated before an audience. *Knowing nothing more as yet,* it is a testable question whether the computer program fails with a beep, or crashes silently. It makes sense to ask whether the computer makes a "sound". But when we have *already* stipulated the presence or absence of acoustic vibrations and auditory experiences, there is nothing *left* to ask after by asking after the presence or absence of sound. The question becomes empty, a dispute over the definition attached to an arbitrary sound-pattern.

I say confidently that (1) taking both boxes in Newcomb's Problem is the decision produced by causal decision theory. I say confidently that (2) causal decision theory renormalizes to an algorithm that takes only box B, if the causal agent is self-modifying, expects to face a Newcomb's Problem, considers the problem in advance, and attaches no intrinsic utility to adhering to a particular ritual of cognition. Having already made these two statements, would I say anything *more* by saying whether taking both boxes is *rational?*

That would be one way to declare a stalemate on Newcomb's Problem. But I do not think it is an appropriate stalemate. Two readers may both agree with (1) and (2) above and yet disagree on whether they would, themselves, in the moment, take two boxes or only box B. This is a disparity of actions, not necessarily a disparity of beliefs or morals. Yet if lives are at stake, the disputants may think that they have some hope of persuading each other by reasoned argument. This disagreement is not unrelated to the question of whether taking both boxes is "rational". So there is more to say.

Also, the initial form of the question grants a rather privileged position to causal decision theory. Perhaps my reader is not, and never has been, a causal decision theorist. Then what is it to my reader that causal decision theory endorses taking both boxes? What does my reader care which theory causal decision theory renormalizes to? What does causal decision theory have to do with rationality? From this perspective also, there is more to say.

Here is a possible resolution: suppose you found some attractive decision theory which behaved like causal decision theory on action-determined problems, behaved like Gloria on decision-determined problems, and this theory was based

on simple general principles appealing in their own right. There would be no reason to regard causal decision theory as anything except a special case of this more general theory. Then you might answer confidently that it was rational to take only box B on Newcomb's Problem. When the tree falls in the forest and someone *does* hear it, there is no reason to say it does not make a sound.

But you may guess that, if such a general decision theory exists, it is to some greater or lesser extent counterintuitive. If our intuitions were already in perfect accord with this new theory, there would be nothing *appealing* about the intuition that we should take both boxes because our action cannot affect the content of box B. Even one-boxers may see the causal intuition's appeal, though it does not dominate their final decision.

Intuition is not sovereign, nor unalterable, nor correct by definition. But it takes *work,* a mental effort, to reject old intuitions and learn new intuitions. A sense of perspective probably helps. I would guess that the physics student who says, "How strange is the human mind, that we think space is flat!" masters General Relativity more readily than the physics student who says, "How strange is the universe, that space is curved!" (But that is only a guess; I cannot offer statistics.) For either physics student, unlearning old intuitions is work. The motive for the physics student to put in this hard work is that her teachers tell her: "Space is curved!" The physics student of pure motives may look up the relevant experiments and conclude that space really is curved. The physics student of impure motives may passively acquiesce to the authoritative voice, or conclude that treating space as flat will lead to lower exam scores. In either case, there is a convincing motive - experimental evidence, social dominance of a paradigm - to work hard to unlearn an old intuition.

This manuscript is addressed to students and professionals of a field, decision theory, in which previously the dominant paradigm has been causal decision theory. Students who by intuition would be one-boxers, are told this is a naive intuition - an intuition attributed to evidential decision theory, which gives clearly wrong answers on other problems. Students are told to unlearn this naive one-box intuition, and learn in its place causal decision theory. Of course this instruction is not given with the same force as the instruction to physics students to give up thinking of space as flat. Newcomb's Problem is not regarded as being so settled as that. It is socially acceptable to question causal decision theory, even to one-box on Newcomb's Problem, though one is expected to provide polite justification for doing so. Yet I ask my readers, not only to put in the mental concentration to unlearn an intuition, but even to unlearn an intuition they previously spent time and effort learning.

Part I of this manuscript is devoted to providing my readers with a motive for putting forth the hard work to learn new intuitions - to sow dissatisfaction with causal decision theory - to evoke a seeking of something better - to create a space in your heart where a new decision theory could live.

I have labored to dispel the prejudice of naivete, the presumption of known folly, that hangs over the one-box option in Newcomb's Problem, and similar choices. I have labored to show that the one-box option and similar choices have interesting properties, such as dynamic consistency, which were not taken into consideration in those early analyses that first cast a pallour of presumptive irrationality on the option. So that if I propose a new theory, and the new theory should take only box B in Newcomb's Problem, my professional readers will not groan and say, "That old chestnut again." The issue is not easily evaded; any general decision theory I proposed which did *not* one-box on Newcomb's Problem would be reflectively inconsistent.

In my labors in Part I, I have sought to illustrate *general* methods for the repair of broken decision theories. I know of specific problems that this manuscript does *not* solve - open questions of decision theory that are entirely orthogonal to the dilemmas on which this manuscript seeks to make progress. Perhaps in the course of solving these other problems, all the theory I hope to present, must needs be discarded in favor of a more general solution. Or someone may discover flaws of the present theory, specific failures on the set of problems I tried to address. If so, I hope that in the course of solving these new problems, future decision theorists may find insight in such questions as:

- What algorithm would this agent prefer to his current one?
- Can I identify a class of dilemmas which the old theory solves successfully, and of which my new dilemma is not a member?
- Is there a superclass that includes both the new dilemma and the old ones?
- What algorithm solves the superclass?

Let future decision theorists also be wary of reasoning from the apparent "absurdity" of momentary reasoning, apart from the outcomes that accrue to such algorithms; for otherwise our explicit theories will never produce higher yields than our initial intuitions.

If we cannot trust the plainness of plain absurdity, what is left to us? Let us look to outcomes to say what is a "win", construct an agent who systematically wins, and then ask what this agent's algorithm can say to us about decision theory. Again I offer an analogy to physics: Rather than appealing to our intuitions to tell us that space is flat, we should find a mathematical theory that systematically predicts our observations, and then ask what this theory has to say about our spatial intuitions. Finding that some agents systematically become poor, and other agents systematically become rich, we should look to the rich agents to see if they have anything intelligent to say about fundamental questions of decision theory. This is not a hard-and-fast rule, but I think it a good idea in every case, to pay close attention to the richest agent's reply. I suggest that *rather than using intuition to answer basic questions of decision theory and then using the answers*

to construct a formal algorithm, we should first construct a formal agent who systematically becomes rich and then ask whether her algorithm presents a coherent viewpoint on basic questions of decision theory.

Suppose we carefully examine an agent who systematically becomes rich, and try *hard* to make ourselves sympathize with the internal rhyme and reason of his algorithm. We try to adopt this strange, foreign viewpoint as though it were our own. And then, after enough work, it all starts to make *sense* - to visibly reflect new principles appealing in their own right. Would this not be the best of all possible worlds? We could become rich *and* have a coherent viewpoint on decision theory. If such a happy outcome is possible, it may require we go along with prescriptions that at *first* seem absurd and counterintuitive (but nonetheless make agents rich); and, rather than reject such prescriptions out of hand, look for underlying coherence - seek a revealed way of thinking that is not an absurd distortion of our intuitions, but rather, a way that is principled though different. The objective is not just to adopt a foreign-seeming algorithm in the expectation of becoming rich, but to alter our intuitions and find a new view of the world - to, not only see the light, but also absorb it into ourselves.

Gloria computes a mapping from agent decisions to experienced (stochastic) outcomes, and chooses a decision that maximizes expected utility over this mapping. Gloria is not the general agent we seek; Gloria is defined *only* over cases where she has full knowledge of a problem in which the problem's mechanism relies on no property of the agents apart from their decisions. Part II of this manuscript introduces a general decision theory which, among its other properties, yields Gloria as a special case given full knowledge and decision-determination.

Part II begins almost from scratch, because Part II attempts to justify individually each of the principles which combine to yield this general decision theory. These principles may, or may not, seem absurd to you. If you are willing to go along with them temporarily - not just for the sake of argument, but trying truly to see the world through those lenses - I hope that you will arrive to a view of decision theory that makes satisfying, coherent sense in its own right; though it was momentarily counterintuitive, relative to initial human intuitions. I will ask my readers to adopt new intuitions regarding *change,* and *control;* but I do my best to justify these principles as making sense in their own right, not just being the credo of the richest agent.

The purpose of Part I has not been to *justify* the theory propounded in Part II, but rather to create a place in your heart for a new decision theory - to convince hardened decision theorists not to *automatically* reject the theory of Part II on the grounds that it absurdly one-boxes in Newcomb's Problem. The purpose of Part I has been to dissuade the reader of some prevailing presumptions in current decision theory (as of this writing), and more importantly, to convince you that *intuition* should not be sovereign judge over decision theories. Rather it is

legitimate to set out to reshape intuitions, even very deep intuitions, if there is some prize - some improvement of agent outcomes - thereby to be gained. And perhaps you will demand that the principle be justified in its own right, by considerations beyond cash in hand; but you will not dismiss the principle *immediately* for the ultimate and unforgivable crime of intuitive absurdity. At the least, pockets stuffed full of money should, if not convince us, convince us to hear out what the agent has to say.

In all of Part I, I have said little upon the nature of rationality, not because I think the question is sterile, but because I think rationality is often best pursued without explicit appeal to rationality. For that may only make our prior intuitions sovereign. The Way justified by citing "The Way" is not the true Way. But now I will reveal a little of what rationality means to me. If Part I has still failed to create a space in your heart for a new decision theory; if you are still satisfied with classical causal decision theory and the method of arguing from intuitive absurdity; if you do not think that dynamic consistency or reflective consistency relate at all to "rationality"; then here is one last attempt to sway you:

Suppose on a Newcomb's Problem that the Predictor, in 10% of cases, fills box B *after* you take your actual action, depending on your actual action; and in 90% of cases fills box B depending on your predicted decision, as before. Where the Predictor fills the box after your action, we will say the Predictor "moves second"; otherwise the Predictor is said to "move first". You know that you will face this modified Newcomb's Problem. Though you are a causal decision theorist, you plan to choose only box B; for there is a 10% chance that this action will directly bring about a million dollars in box B.

Before the time when the Predictor is to make Its move in the 90% of cases where the Predictor moves first, your helpful friend offers to tell you truly this fact, whether the Predictor will move first or second on this round. A causal decision theorist must say, "No! Do not tell me." For the causal decision theorist expects, with 90% probability, to hear the words: "The Predictor will move first on this round", in which case the causal decision theorist knows that he will choose both boxes and receive only $1,000. But if the causal decision theorist does not know whether the Predictor moves first or second, then he will take only box B in all cases, and receive $1,000,000 in all cases; and this the causal decision theorist also knows. So the causal decision theorist *must avoid this piece of true knowledge.* If someone tries to tell him the real state of the universe, the causal decision theorist must *stuff his fingers in his ears!* Indeed, the causal decision theorist should *pay* not to know the truth.

This variant of Newcomb's Problem occurred to me when, after I had previously decided that causal decision theory was dynamically inconsistent, I ran across a reference to a paper title that went something like, "Dynamic inconsistency can lead to negative information values." Immediately after reading the title, the above variant of Newcomb's Problem occurred to me. I did not even need to

read the abstract. So unfortunately I now have no idea whose paper it was. But that is another argument for treating causal decision theory as dynamically inconsistent; it quacks like that duck. In my book, assigning negative value to information - being willing to *pay* not to confront reality - is a terrible sign regarding the choiceworthiness of a decision theory!

10: Review: Pearl's formalism for causal diagrams.

Judea Pearl, in his book *Causality* (Pearl 2000), explains and extensively defends a framework for modelling counterfactuals based on directed acyclic graphs of causal mechanisms. I find Pearl's arguments for his framework to be extremely compelling, but I lack the space to reproduce here his entire book. I can only give a brief introduction to causal diagrams, hopefully sufficient to the few uses I require (causal diagrams have many other uses as well). The interested reader is referred to Pearl (2000).

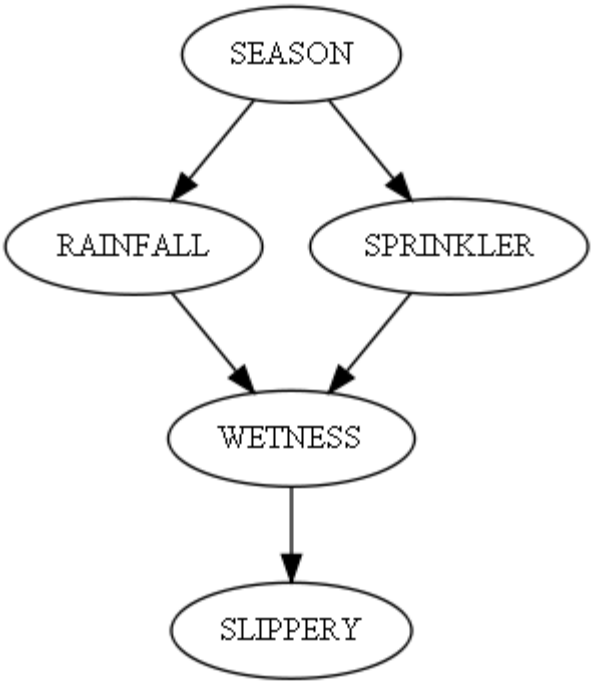

Figure 1:

Suppose we are researchers in the fast-expanding field of sidewalk science, and we are interested in what causes sidewalks to become slippery, and whether it has anything to do with the season of the year. After extensive study we propose this set of causal mechanisms:

The *season* variable influences how likely it is to rain, and also whether the sprinkler is turned on. These two variables in turn influence how likely the sidewalk is to be wet. And whether or not the sidewalk is wet determines how likely the sidewalk is to be slippery.

This directed acyclic graph of causal connectivity is qualitative rather than quantitative. The graph does not specify *how* likely it is to rain during summer; it only says that seasons affect rain in some way. But by attaching conditional probability distributions to each node of the graph, we can generate a joint probability for any possible outcome. Let the capital letters X1, X2, X3, X4, X5 stand for the variables SEASON, RAINFALL, SPRINKLER, WETNESS, and SLIPPERY. Let x1, x2, x3, x4, x5 stand for possible specific *values* of the five variables above. Thus, the variables x1=summer, x2=no rain, x3=on, x4=damp, and x5=treacherous would correspond to the empirical observation that it is summer, it is not raining, the

sprinkler is on, the sidewalk is "damp", and the degree of slipperiness is "treacherous"[11]. We want to know what probability our hypothesis assigns to this empirical observation.

Standard probability theory[12] makes it a tautology to state for any positive probability:

p(x1x2x3x4x5) = p(x1)p(x2|x1)p(x3|x2x1)p(x4|x3x2x1)p(x5|x4x3x2x1)

The directed causal graph shown in Figure 1 makes the falsifiable, non-tautological claim that the observed probability distribution will always factorize as follows:

p(x1x2x3x4x5) = p(x1)p(x2|x1)p(x3|x1)p(x4|x3x2)p(x5|x4)

Intuitively, we might imagine that we first ask what the probability is of it being summer (25%), then the probability that it is not raining in the summer (80%), then the probability that the sprinkler is on in the summer (30%), then the probability that the sidewalk is damp when it is not raining and the sprinkler is on (99%), then the probability that the sidewalk is treacherous when damp (80%). Implicit in this formula is the idea that only certain events *directly* affect other events. We write p(x3|x1) instead of the tautological p(x3|x2x1) because we assume that whether the sprinkler is on does not affect the rain, nor vice versa. Once we already know that it isn't raining and that the sprinkler is on, we no longer need to know the season in order to figure out how wet the sidewalk is; we multiply by p(x4|x3x2) instead of p(x4|x3x2x1) and (by hypothesis) require the two quantities to be identical. That is how we compute the probability distribution which our causal hypothesis predicts.

Inference works differently from causation. We know that the rooster's crow does not cause the sun to rise, but we *infer* that the sun will rise if we *observe* the rooster crow. Raining causes the sidewalk to be wet, but we do not say that wet sidewalks cause rain. Yet if we see a wet sidewalk we infer a greater probability that it is raining; and also if we see it raining we infer that the sidewalk is more likely to be wet. In contrast to logical deduction, probabilistic inference is always bidirectional; if we infer wet sidewalks from rain we must necessarily infer rain from wet sidewalks[13]. How then are we to cash out, as falsifiable predictions, statements about *asymmetrical* causation? Suppose we have three hypotheses:

[11] If we demand quantitative predictions, we could suppose that the day is July 11th, the rainfall is 0 inches, the sprinkler is on, the sidewalk has 100 milligrams of water per square centimeter, and the sidewalk's coefficient of static fraction is 0.2.

[12] The notation p(a1) stands for "the probability of a1". p(a1a2) stands for "the probability of a1 and a2", which may also be written p(a1, a2) or p(a1 & a2). p(a1|a2) stands for "the probability of a1 given that we know a2". Bayes's Rule defines that p(a1|a2) = p(a1a2)/p(a2).

[13] In deductive logic, "P implies Q" does not imply "Q implies P". However, in probabilistic inference, if conditioning on A increases the probability of B, then conditioning on B must necessarily increase the probability of A. p(a1|a2) > p(a1) implies p(a1a2)/p(a2) > p(a1) implies p(a1a2) > p(a1)p(a2) implies p(a1a2)/p(a1) > p(a2) implies p(a2|a1) > p(a2). QED.

(A) Rain causes wet sidewalks. (B) Wet sidewalks cause rain. (C) Pink rabbits from within the hollow Earth[14] cause both rain and wet sidewalks. Any of these three causal diagrams, when computed out to probability distributions, could lead to the observed *non-experimental* correlation between wet sidewalks and rain.

In intuitive terms, we can distinguish among the three hypotheses as follows. First, we pour water on the sidewalk, and then check whether we observe rain. Since no rain is observed, we conclude that wet sidewalks do not cause rain. This falsifies (B) and leaves hypotheses (A) and (C). We send up a plane to seed some clouds overhead, making it rain. We then check to see whether we observe wet sidewalks, and lo, the sidewalk is wet. That falsifies (C) and leaves us with this *experimentally* observed asymmetry[15]: Making rain causes a wet sidewalk, but wetting the sidewalk does not cause rain.

We begin to approach a way of describing the distinction between evidential decision theory and causal decision theory - there is a difference between *observing* that the sidewalk is wet, from which we infer that it may be raining, and *making* the sidewalk wet, which does not imply a higher probability of rain. But how to formalize the distinction?

In Judea Pearl's formalism, we write p(y|x^) to denote[16] "the probability of observing y if we set variable X to x" or "the probability of y given that we do x". To compute this probability, we modify the causal diagram by deleting all the

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We can probabilistically infer a higher probability of B after observing A iff p(A & B) > p(A)p(B), that is, the joint probability of A and B is higher than it would be if A and B were independent. This phrasing renders the symmetry visible.

We say A and B are *dependent* iff p(A & B) != p(A)p(B). We say A and B are *independent* iff p(A & B) = p(A)p(B), in which case we can infer nothing about B from observing A or vice versa.

[14] Pink rabbits from within the hollow Earth are also known as "confounding factors", "spurious correlations", "latent causes", and "third causes". For some time the tobacco industry staved off regulation by arguing that the observed correlation between smoking and lung cancer could have been caused by pink rabbits from within the hollow Earth who make people smoke and then give them lung cancer. The correlation *could* have been caused by pink rabbits, but it was *not,* and this is an important point to bear in mind when someone says "correlation does not imply causation".

[15] Contrary to a long-standing misconception, asymmetrical causality can also be observed in (the simplest explanation of) non-experimental, non-temporal data sets. Presume that all our observations take place during the summer, eliminating the seasonal confounding between sprinklers and rain. Then if "wet sidewalks cause both rain and sprinkler activations", RAINFALL and SPRINKLER will be *dependent*, but conditioning on WET will make them *independent.* That is, we will have p(rain & sprinkler) != p(rain)p(sprinkler), and p(rain & sprinkler|wet) = p(rain|wet)p(sprinkler|wet). If "rain and sprinkler activations both cause wet sidewalks" then we will find that rain and sprinklers are independent, unless we observe the sidewalk to be wet, in which case they become dependent (because if we know the sidewalk is wet, and we see it is not raining, we will know that the sprinkler is probably on). This testable consequence of a directed causal graph is a core principle in algorithms that infer directionality of causation from non-experimental non-temporal data. For more details see Pearl (2000).

[16] Despite the resemblance of the notations p(y|x) and p(y|x^), the former usage denotes Bayesian conditionalization, while the latter usage denotes a function from X to the space of probability distributions over Y.

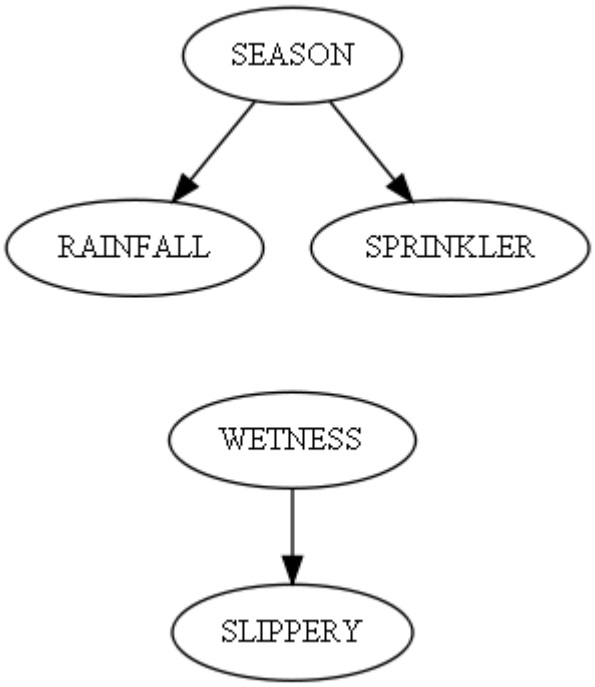
arrows which lead to X, i.e., delete the conditional probability for X from the joint distribution.

Suppose that we pour water on the sidewalk - set variable X4 to the value "wet", which we shall denote by x4. We would then have a new diagram and a new distribution:

p(x1x2x3x5|x^4) = p(x1)p(x2|x1)p(x3|x1)p(x5|x4)

Note that the factor p(x4|x3x2) has been deleted from the computation of the new joint distribution, since X4 now takes on the fixed value of x4. As expected, the probabilities for the season, rainfall, and sprinkler activation are the same as before we poured water on the sidewalk.

FIGURE 2:



Only the slipperiness of the sidewalk is affected by our action. Note also that this new equation is *not* the correct way to compute p(x1x2x3x5|x4) - if we *observed* a wet sidewalk, it would change our inferred probabilities for rainfall, the season, etc.

To simulate an experimental manipulation within a causal diagram, we sever the manipulated variable from its parents. Correspondingly, we delete the manipulated variable's conditional probability from the joint distribution over the remaining variables. Still another way of viewing this operation is by writing the causal diagram as a series of *deterministic* computations:

X1 := f1(u1)
X2 := f2(X1, u2)
X3 := f3(X1, u3)
X4 := f4(X2, X3, u4)
X5 := f5(X4, u5)

Here the various ui are the error terms or probabilistic components, representing background variables which we choose not to take into account in our model. The := operators are to be understood as denoting *computations,* or *assignments* as of a programming language, rather than algebraic *relations.* In algebra, the equation y = x + b is identical, as a mathematical object, to the equation x = y - b. But in that mathematics which treats computer programs as formal mathematical objects, the assignment y := x + b is a different computation from the assignment x := y - b. To assess the affect of the experimental intervention p(x1x2x3x5|x^4), we delete the assignment X4 := f4(X2, X3, u4) and substitute the assignment X4 := x4. When we carry through the computation, we will find a result that reflects the predicted probability distribution for the causal diagram under experimental intervention.

This formal rule for computing a prediction for an experimental intervention, given a causal diagram, Pearl names the *do-calculus.* p(y|x^) may be read aloud as "probability of y given do x".

Computer programmers should find the above quite intuitive. Mathematicians[17] may find it jarring, wondering why the elegant algebra over probability distributions should transform into the computational blocks of causal diagrams. Statisticians may wince, recalling harsh instruction to avoid the language of cause and effect. For a full defense, one should consult the book *Causality*. Since it is not my main purpose to defend the notion of causality, I contribute only these remarks:

- Since causal diagrams compute out to probability distributions, the mathematical object called a "causal diagram" can plug into any socket that requires the mathematical object called a "probability distribution" - while also possessing additional useful properties of its own.
- Causal diagrams can explicitly represent compactness in a raw probability distribution, such as probabilistic independences and relations between variables. Some means of encoding the regularities in our observations is needed to invoke Occam's Razor, which underlies the inductive labor of science.
- A raw probability distribution over N discrete variables with M possible values has M^N - 1 degrees of freedom. This is too much flexibility, too much license to fit the data, too little yield of predictive accuracy for each

[17] Except constructivist mathematicians, who are accustomed to working with computations as the basic elements of their proofs.

adjustment to the model. The mathematical object called a "probability distribution" is not a productive scientific hypothesis; it is a prediction produced by a productive hypothesis.

- All actual thinking takes place by means of cognition, which is to say, computation. Thus causal diagrams, which specify *how* to compute probabilities, have a virtue of real-world implementability lacking in the mathematical objects that are raw probability distributions.
- Perhaps the greatest *scientific* virtue of causal diagrams is that a *single* causal hypothesis predicts a non-experimental distribution *plus* additional predictions for any performable experiment. All of these predictions are independently checkable and falsifiable, a severe test of a hypothesis. The formalism of probability distributions does not, of itself, specify any required relation between a non-experimental distribution and an experimental distribution - implying infinite freedom to accomodate the data.

11: Translating standard analyses of Newcomblike problems into the language of causality.

With the language of Pearl's causality in hand, we need only one more standard ingredient to formally describe causal decision theory and evidential decision theory. This is expected utility maximization, axiomatized in (von Neumann and Morgenstern 1953). Suppose that I value vanilla ice cream with utility 5, chocolate ice cream with utility 10, and I assign utility 0 to the event of receiving nothing. If I were an expected utility maximizer I would trade a 10% probability of chocolate ice cream (and a 90% probability of nothing) for a 30% probability of vanilla ice cream, but I would trade a 90% probability of vanilla ice cream for a 50% probability of chocolate ice cream.

"Expected utility" derives its name from the mathematical operation, expectation, performed over utilities assigned to outcomes. When we have a quantitative function f(X) and some probability distribution over X, our expectation of f(X) is the quantity

$$E[f(X)] = \sum_x f(x)p(x)$$

This is simply the weighted average of f(X), weighted by the probability function p(X) over each possibility in X. In expected utility, the utility u(X) is a measure of the utility we assign to each possible outcome - each possible consequence that could occur as the result of our actions. When combined with some conditional probability distribution for the consequences of an action, the result is a measure [18] of *expected utility* for that action. We can then determine which of two actions

[18] Utility functions are equivalent up to a positive affine transformation u'(x) = au(x) + b. A utility function thus transformed will produce identical preferences over actions. Thus, both utility and expected utility are referred to as "measures".

we prefer by comparing their utilities and selecting the one with a higher expected utility. Or, given a set of possible actions, we can choose an action with maximal expected utility (an action such that no other action has higher expected utility). An agent that behaves in this fashion is an *expected utility maximizer*.

Human beings are not expected utility maximizers (Kahneman and Tversky 2000) but it is widely held that a rational agent should be[19] (Von Neumann and Morgenstern 1944).

We can now easily describe the *formal* difference between evidential and causal decision algorithms:

Evidential decision algorithm: $Eu(a) = \sum_x u(x)p(x|a)$

Causal decision algorithm: $Eu(a) = \sum_x u(x)p(x|a^)$

Let's begin by translating the classic analyses of Newcomb's Problem into the language of causality. A superintelligent Predictor arrives from another galaxy and sets about playing Newcomb's game: The Predictor sets out a transparent box A filled with a thousand dollars, and an opaque box B. The Predictor places a million dollars in box B if and only if the Predictor predicts that you will take only box B. Historically, the Predictor has always been accurate[20]. Then the Predictor leaves. Do you take both boxes, or only box B?

Let the action aB represent taking the single box B, and action aAB represent taking two boxes. Let the outcome B$ represent the possibility that box B is filled with $1,000,000, and the outcome B0 represent the possibility that box B is empty. Then the game has these conceptually possible outcomes:

	B$:	B0:
aB:	aB,B$: $1,000,000	aB,B0: $0
aAB:	aAB,B$: $1,001,000	aAB,B0: $1000

Let us suppose that historically half the subjects took only box B and half the subjects took both boxes, and the Predictor always predicted accurately. Then we observed this joint frequency distribution over actions and outcomes:

	B$:	B0:

[19] Note that the von Neumann - Morgenstern axiomatization of expected utility makes no mention of the philosophical commitments sometimes labeled as "utilitarianism". An agent that obeys the expected utility axioms need not assign any particular utility to happiness, nor value its own happiness over the happiness of others, regard sensory experiences or its own psychological states as the only meaningful consequences, etc. Expected utility in our sense is simply a mathematical constraint, fulfilled when the agent's preferences have a certain structure that forbids, e.g., nontransitivity of preferences (preferring A to B, B to C, and C to A).

[20] We also suppose that the Predictor has demonstrated good *discrimination*. For example, if everyone tested took only box B, and the Predictor was always right, then perhaps the Predictor followed the algorithm "put a million dollars in box B every time" rather than actually *predicting*.

aB:	aB,B$: 50%	aB,B0: 0%[21]
aAB:	aAB,B$: 0%	aAB,B0: 50%

An evidential decision agent employs the standard operations of marginalization, conditionalization, and Bayes's Rule to compute conditional probabilities. (Note that these operations require only a distributional representation of probability, without invoking causal diagrams). An evidential agent concludes that the actions aB and aAB imply the following probability distributions over outcomes:

	B$:	B0:
aB:	p(B$|aB): 100%[22]	p(B0|aB): 0%
aAB:	p(B$|aAB): 0%	p(B0|aAB): 100%

The expected utility of aB therefore equals u($1,000,000) and the expected utility of aAB equals u($1,000). Supposing the agent's utility function to be increasing in money, an evidential agent chooses aB by the rule of expected utility maximization.

Now consider the causal agent. The causal agent requires the probabilities:

	B$:	B0:
aB:	p(B$|a^B)	p(B0|a^B)
aAB:	p(B$|a^AB)	p(B0|a^AB)

Since the do-calculus operates on causal diagrams, we cannot compute these probabilities without a causal diagram of the Newcomb problem:

Figure 3 shows a causal diagram which can account for all dependencies historically observed in the non-experimental distribution: The Predictor (P) observes the state of mind of a causal decision agent (C) at 7AM, represented by a link from C7AM to P (since, when P observes C, P's state becomes a function of C's state). P, observing that C is a causal decision theorist, fills box B with $0 to punish C for his rationality. Then at 8AM, C is faced with the Predictor's game, and at node A must choose action aB or aAB. Being a causal decision theorist, C chooses action aAB. This causal diagram explains the observed

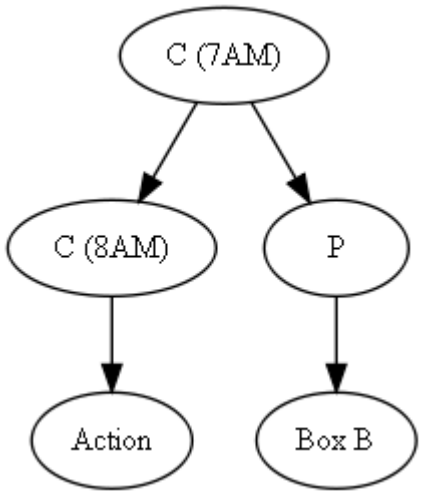


Figure 3:

[21] Note that postulating an observed frequency of 0% may break some theorems about causal diagrams which require a positive distribution (a probability distribution that is never zero).

[22] A wise Bayesian will never claim a probability of *exactly* 1.0. "Once I assign a probability of 1 to a proposition, I can never undo it. No matter what I see or learn, I have to reject everything that disagrees with the axiom. I don't like the idea of not being able to change my mind, ever." (Smigrodzki whenever). For the sake of simplifying calculations, we suppose the historical sample is large enough that an evidential agent is "effectively certain", 1.0 minus epsilon.

dependency between variable A (the action) and variable B (the state of box B) by attributing it to a confounding mutual cause, C's state of mind at 7AM. Had C been an evidential decision agent, the Predictor would have filled B with $1,000,000 at 7:30AM and C would have chosen aAB at 8AM.

The causal decision agent, faced with a decision at node A, computes *interventional* probabilities by severing the node A from its parents and substituting the equations A := aB and A := aAB to compute the causal effect of choosing aB or aAB respectively:

	B$:	B0:
aB:	p(B$|a^B): 0%	p(B0|a^B): 100%
aAB:	p(B$|a^AB): 0%	p(B0|a^AB): 100%

This reflects the intuitive argument that underlies the choice to take both boxes: "The Predictor has already come and gone; therefore, the contents of box B cannot depend on what I choose."

From the perspective of an evidential decision theorist, this is the cleverest argument ever devised for predictably losing $999,000 dollars.

We now move on to our second Newcomblike problem. In (this variant of) Solomon's Problem, we observe the following:

1. People who chew gum have a much higher incidence of throat abscesses;
2. In test tube experiments, chewing gum is observed to kill the bacteria that form throat abscesses;
3. Statistics show that conditioning on the gene CGTA reverses the correlation between chewing gum and throat abscesses.[23]

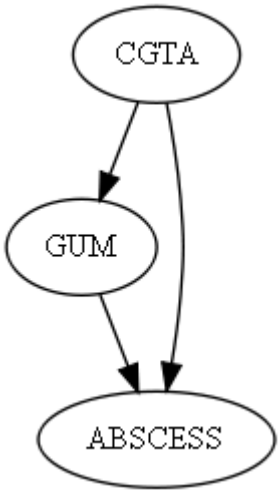


Figure 4:

We think this happens because the gene CGTA both causes throat abscesses and influences the decision to chew gum. We therefore explain the observed distribution using figure 4 and the formula:

$p(x1x2x3) = p(x1)p(x2|x1)p(x3|x2x1)$[24]

The causal decision theorist severs the node "chew gum" from its parent, CGTA, in order to evaluate the causal effect of chewing gum versus not chewing gum. The new formula is $p(x3|x^2) = \sum_{x1} p(x1x3|x^2) = \sum_{x1} p(x1)p(x3|x2x1)$. The causal decision theorist thus begins by assuming his probability of possessing gene CGTA

[23] That is, if we divide the subjects into separate pools according to the presence or absence of CGTA, chewing gum appears to protect both pools against throat abscesses. p(abscess|gum) > p(abscess), but p(abscess|gum,CGTA) < p(abscess|CGTA) and p(abscess|gum,~CGTA) < p(abscess|~CGTA). Such a situation is known as "Simpson's Paradox", though it is not a paradox.

is the same as that for the general population, and then assessing his probability of developing a throat abscess given that he does (or does not) chew gum. The result is that chewing gum shows a higher expected utility than the alternative. This seems to be the sensible course of action.

The evidential decision theorist would, on first sight, seem to behave oddly; using standard probability theory yields the formula $p(x3|x2) = \sum_{x1} p(x1|x2)p(x3|x2x1)$. Thus, the evidential decision theorist would first update his probability of possessing the gene CGTA in the light of his decision to chew gum, and then use his decision plus the updated probability of CGTA to assess his probability of developing throat cancer. This yields a lower expected utility for chewing gum.

Tickle defense and meta-tickle defense.

The "tickle defense" promulgated by Eels (1982) suggests that as soon as an evidential agent notices his *desire* to chew gum, this evidence already informs the agent that he has gene CGTA - alternatively the agent might introspect and find that he has no desire to chew gum. With the value of the CGTA variable already known and fixed, the decision to chew gum is no longer evidence about CGTA and the only remaining "news" about throat abscesses is good news. p(abscess|gum) may be greater than p(abscess), but p(abscess|gum, cgta+) < p(abscess|cgta+) and similarly with p(abscess|gum, cgta-). The tickle defense shows up even more clearly in this variant of Solomon's Problem:

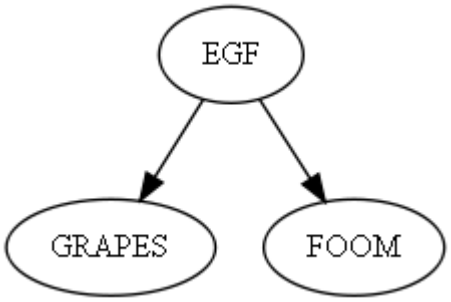


Figure 5:

Here the same gene causes people to like eating grapes and also causes people to spontaneously combust, but the spontaneous combustion does not cause people to eat grapes nor vice versa. If you find that you *want* to eat grapes, you may as well go ahead and eat them, because the already-observed fact that you *want* to eat grapes already means that you have Gene EGF, and the actual act of eating grapes has no correlation to spontaneous combustion once the value of EGF is known. This is known as "screening off". Considered in isolation, the variables GRAPES and FOOM are correlated in our observations - p(grapes,foom) > p(grapes)*p(foom), because if you eat grapes you probably have EGF and EGF may make you spontaneously combust. But if you observe the value of the variable EGF, then this *screens off* FOOM from GRAPES (and GRAPES from FOOM), rendering the variables independent. According to the causal diagram D, p(GRAPES,FOOM|EGF) must equal p(GRAPES|EGF)*p(FOOM|EGF) for all specific values of these variables.

[24] This formula equates to the tautological one. A fully connected causal graph requires no independences and hence makes no testable predictions regarding dependences until an experimental manipulation is performed.

So far, so good. It seems that a single decision theory - evidential decision theory plus the tickle defense - walks off with the money in Newcomb's Problem, and also chews protective gum in the throat-abscess variant of Solomon's Problem.

Yet the theorists behind the tickle defense did not rest on that accomplishment, but continued to elaborate and formalize their theory. Suppose that you cannot observe yourself wanting to chew gum - you lack strong cognitive abilities of introspection. Or suppose the influence on your cognition is such that you can't easily determine your own true motives[25]. Does an evidential theorist then avoid chewing gum, or the equivalent thereof? No, says Eels: Once you make a tentative decision, that decision can be taken into account as evidence and you can reconsider your decision in light of this evidence. This is the meta-tickle defense (Eells 1982) and it is rather complicated, since it introduces an iterative algorithm with a first-order decision, a second-order decision, continuing ad infinitum or until a stable fixed point is found. The meta-tickle defense requires us to assign probabilities to our own decisions and sometimes to revise those probabilities sharply, and there is no guarantee that the algorithm terminates.

In fact, Eels went on to say that his meta-tickle defense showed that an evidential decision theorist would take both boxes in Newcomb's Problem![26]

What we would ideally like is a version of the tickle defense that lets an evidential theorist chew protective gum, and also take only box B in Newcomb's Problem. Perhaps we could simply use the tickle defense on one occasion but not the other? Unfortunately this answer, pragmatic as it may seem, is unlikely to satisfy a decision theorist - it has not been formalized, and in any case one would like to know *why* one uses the tickle defense on one occasion but not the other.

12: Review: The Markov condition

The Markov Condition requires statistical independence of the error terms, the ui in the computations described in section 10:. This is a mathematical assumption inherent in the formalism of causal diagrams; if reality violates the assumption, the causal diagram's prediction will not match observation.

Suppose that I roll a six-sided die and write down the result on a sheet of paper. I dispatch two sealed copies of this paper to two distant locations, Outer Mongolia and the planet Neptune, where two confederates each roll one additional six-sided die and add this to the number from the piece of paper. Imagine that you are observing this scenario, and that neither of my confederates has yet opened their sealed packet of paper, rolled their dice, or announced their sums.

[25] "Power corrupts," said Lord Acton, "and absolute power corrupts absolutely."

[26] At this time the widespread opinion in the field of decision theory was that taking both boxes was the "rational" choice in Newcomb's Problem and that the Predictor was simply punishing two-boxers. Arguing that ticklish agents would take both boxes was, in the prevailing academic climate, an argument seen as supporting the tickle defense.

One *ad hoc* method for modeling this scenario might be as follows. First, I consider the scenario in Mongolia. The Mongolian confederate's six-sided die might turn up any number from 1 to 6, and having no further useful information, by the Principle of Indifference[27] I assign a probability of 1/6 to each number. Next we ask, *given* that the Mongolian die turned up 5, the probability that each number between 2 and 12 will equal the *sum* of the Mongolian die and the number in the sealed envelope. If the Mongolian die turned up 5, it would seem that the sums 6, 7, 8, 9, 10, and 11 are all equally possible (again by the Principle of Indifference, having no further information about the contents of the envelope). So we model the Mongolian probabilities using two probability distributions, DM for the result of the Mongolian die, and P(SM|DM) for the Mongolian sum given the Mongolian die. And similarly for the Neptunian die. The rolling of dice on Neptune is independent of the rolling of dice in Mongolia, that is, P(DN|DM) = P(DN). We may be very sure of this, for the confederates are scheduled to roll their dice such that the events are spacelike separated[28], and thus there is no physically possible way that one event can have a causal effect on the other. Then when the Neptunian has rolled her die and gotten a 3, we again have a distribution P(SN|DN) which assigns equal probabilities to the sums 4, 5, 6, 7, 8, and 9. If we write out this computation as a causal diagram, it looks like this:

* Two independent causal chains.

But ah! - this *ad hoc* diagram gives us a false answer, for the subgraphs containing SN and SM are disconnected, necessarily requiring independence of the dice-sum in Mongolia and the dice-sum on Neptune. But both envelopes contain the same number! If we have a sum of 10 in Mongolia, we cannot possible have a sum of 4 on Neptune. A sum of 10 in Mongolia implies that the least number in the envelope could have been 4; and then the sum on Neptune must be at least 5. Because reality violates the Markov assumption relative to our causal diagram, the diagram gives us a false joint distribution over P(SNSM).

What is the Markov condition? To make the Markov condition more visible, let us write out the false-to-fact causal diagram as a set of equations:

```
DM = f1(u1)          p(u1)
SM = f2(DM, u2)      p(u2)
DN = f3(u3)          p(u3)
```

[27] More generally, the Principle of Indifference is a special case of the principle of maximum entropy. This use of the maximum-entropy principle to set prior probabilities is licensed by the indistinguishability and interchangeability of the six labels attached to the six faces of the die, in the absence of any further information (Jaynes 2004).

[28] That is, the two confederates roll their dice in such fashion that it would be impossible for a light ray leaving the Neptunian die-roll to arrive in Mongolia before the Mongolian die rolls, or vice versa. Therefore any talk of the confederates rolling their dice "at the same time" is meaningless nonsense, as is talk of one confederate rolling a die "before" or "after" the other.

SN = f4(DN, u4) p(u4)

This formulation of a causal diagram makes the underlying computations fit into *deterministic* functions; all *probabilism* now resides in a probability distribution over the "error terms" ui. Despite the phrase "error term", the ui are not necessarily errors in the sense of noise - the probability distributions over ui can represent any kind of information that we do not know, including background conditions which would be too difficult to determine in advance. The only requirement is that, *given* the information summarized by the ui (including, e.g., the results of die rolls), the *remaining* mechanisms should be functions rather than probabilities; that is, they should be deterministic. (Pearl and Verma 1991.)

The Markov condition is that the error terms ui should all be *independent* of each other: p(u1u2u3u4) = p(u1)p(u2)p(u3)p(u4). Our dice-rolling scenario violates the Markov condition *relative to* the diagram D because the error terms u2 and u4 are dependent - in fact, u2 = u4.

Can we add a dependency between u2 and u4? This would be represented in a causal diagram by a dashed arc between X2 and X4:

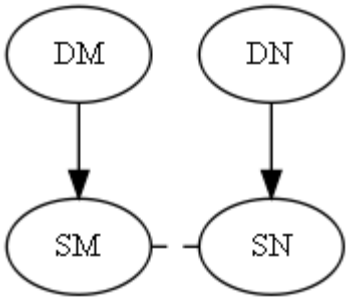


Figure 6:

However, the diagram is now *semi-Markovian,* a condition satisfied when no dependencies exist among the ui except those specified by dashed arcs. Furthermore, the conditional probability formula for p(x1x2x3x4) is no longer valid, that is, p(x1x2x3x4) != p(x4|x3)p(x3)p(x2|x1)p(x1). We can no longer cash out this diagram to a probability distribution.

So how do we resolve a semi-Markovian diagram back to a Markovian diagram? Without difficulty, we rewrite our diagram as follows:

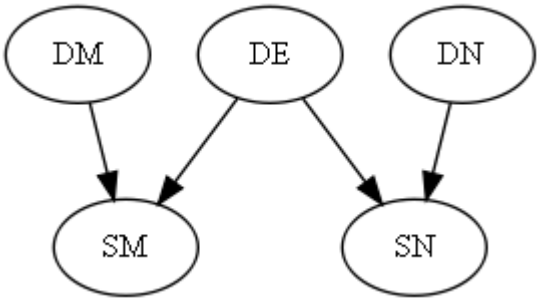


Figure 7:

DE = f1(u1) p(u1)
DM = f2(u2) p(u2)
SM = f3(DE, DM)
DN = f4(u4) p(u4)
SN = f5(DE, DN)

DE here stands for the die-roll that determines the contents of the envelopes dispatched to Neptune and Mongolia. The standard formulation adds error terms at u3 and u5, setting them to fixed values. Personally I would prefer to omit the error terms u3 and u5, since they play no computational role in the functions f3 or f5. Note also that since DM and

DN affect only SM and SN respectively, we could as easily write the causal diagram:

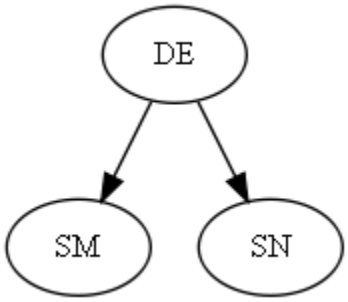


Figure 8:

DE = f1(u1) p(u1)
SM = f2(DE, u2) p(u2)
SN = f3(DE, u3) p(u3)

This more compact diagram also makes it easier to read off that if we observe the value of DE, this renders SN and SM statistically independent of one another. That is, once we know the value in the envelope, knowing the sum on Neptune tells us nothing *more* about the sum in Mongolia. If we observe completely the local physical variables in the preconditions to the two scenarios - if we examine fully the dice and the envelope, before rolling the dice and computing the sum - then there are no correlated random factors in the two scenarios; the remaining error terms are independent. This respects the physical requirement (according to our current understanding of physics) that no physical effect, no arrow of causality in a causal diagram, may cross a spacelike separation between events.[29] *Inference* obeys no such constraint. If you take a matched pair of socks, send a sock in a box to Proxima Centauri, and then show me that the other sock is black, I may deduce immediately that the sock at Proxima Centauri is black. But no influence travels faster than light - only an inference.

The map is not the territory. On learning a new fact, I may write in many changes to my map of the universe, perhaps marking in deductions about widely separated galaxies. But the entire map lies on my table, though it may refer to distant places. So long as my new knowledge does not cause the territory itself to change, Special Relativity is obeyed.

As Pearl points out, we intuitively recognize the importance of the full Markov condition in good explanations. An unexplained correlation shows that a causal explanation is incomplete. If we flip two coins in two widely separated locations and find that both coins produce the same sequence HTHTTTHTHHHH..., on and on for a thousand identical flips, we wouldn't accept the bland explanation, "Oh, that's just an unexplained correlation." We would suspect something interesting happening behind the scenes, something worthy of investigation.

If X and Y correlate, a good explanation should describe a causal effect of X on Y, a causal effect of Y on X, or a confounder which affects both X and Y. A causal diagram containing no such links predicts a probabilistic independence which observation falsifies.

[29] If two events are "spacelike separated", traveling between them requires traveling faster than light.

13: Timeless decision diagrams

I propose that to properly *represent* Newcomblike problems we must augment standard-issue causal diagrams in two ways. I present these two augmentations in turn.

For my first augmentation of standard causal diagrams, I propose that causal diagrams should represent our uncertainty about the results of computations - for example, "What do you get if you multiply six by nine?" It is not particularly difficult to include uncertainty about computations into causal diagrams, but the inclusion must not break underlying mathematical assumptions, as an *ad hoc* fix might do. The chief assumption in danger is the Markov property.

Suppose that I place, in Mongolia and Neptune, two calculators programmed to calculate the result of 678 * 987 and then display the result. As before, the timing is such that the events will be spacelike separated - both events occur at 5PM on Tuesday in Earth's space of simultaneity. Before 5PM on Tuesday, you travel to the location of both calculators, inspect them transistor by transistor, and confirm to your satisfaction that both calculators are physical processes poised to implement the process of multiplication and that the multiplicands are 678 and 987. You do not actually calculate out the answer, so you remain uncertain of which number shall flash on the calculator screens. As the calculators are spacelike separated, it is physically impossible for a signal to travel from one calculator to another. Nonetheless you expect the same signs to flash on both calculator screens, even though you are uncertain *which* signs will flash. For the sake of simplification, I now inform you that the answer is either 669186 or 669168. Would it be fair to say that you assign a probability of 50% to the answer being 669186?

Some statisticians may object to any attempt to describe uncertainty about computations in terms of probability theory, protesting that the product of 678 * 987 is a fixed value, not a random variable. It is nonsense to speak of the probability of the answer being 669186; either the answer is 669186 or it is not. There are a number of possible replies to this, blending into the age-old debate between Bayesian probability theory and frequentist statistics. Perhaps some philosophers would refuse to permit probability theory to describe the value of a die roll written inside a sealed envelope I have not seen - since, the die roll having been written down, it is now fixed instead of random. Perhaps they would say: "The written die result does not have a 1/6 probability of equalling 4; either it equals 4 or it does not."

As my first reply, I would cite the wisdom of Jaynes (1996), who notes that a classical "random" variable, such as the probability of drawing a red ball from a churning barrel containing 30 red balls and 10 white balls, is rarely random - not in any physical sense. To really calculate, e.g., the probability of drawing a red ball after drawing and replacing a white ball, we would have to calculate the placement of the white ball in the barrel, its motions and collisions with other

balls. When statisticians talk of "randomizing" a process, Jaynes says, they mean "making it vastly more complicated". To say that the outcome is *random,* on this theory, is to say that the process is so unmanageable that we throw up our hands and assign a probability of 75%.

The map is not the territory. It may be that the balls in the churning barrel, as macroscopic objects, are actually quite deterministic in their collisions and reboundings; so that someone with a sophisticated computer model could predict precisely whether the next ball would be red or white. But so long as we do not have this sophisticated computer model, a probability of 75% best expresses our ignorance. Ignorance is a state of mind, stored in neurons, not the environment. The red ball does not know that we are ignorant of it. A probability is a way of quantifying a state of mind. Our ignorance then obeys useful mathematical properties - Bayesian probability theory - allowing us to systematically reduce our ignorance through observation. How would you go about reducing ignorance if there were no way to measure ignorance? What, indeed, is the advantage of *not* quantifying our ignorance, once we understand that quantifying ignorance reflects a choice about how to think effectively, and not a physical property of red and white balls?

It also happens that I flipped a coin to determine which of the two values I would list first when I wrote "669186 or 669168". If it is impermissible to say that there is a 50% probability of the answer being 669186, is it permissible to say that there is a 50% probability that the value listed first is the correct one?

Since this is a paper on *decision* theory, there is a much stronger reply - though it applies only to decision theory, not probability theory. There is an old puzzle that Bayesians use to annoy frequentist statisticians. Suppose we are measuring a physical parameter, such as the mass of a particle, in a case where (a) our measuring instruments show random errors and (b) it is physically impossible for the parameter to be less than zero. A frequentist refuses to calculate any such thing as the "probability" that a fixed parameter bears some specific value or range of values, since either the fixed parameter bears that value or it does not. Rather the frequentist says of some experimental procedure, "This procedure, repeated indefinitely many times, will 95% of the time return a range that contains the true value of the parameter". According to the frequentist, this is all you can *ever* say about the parameter - that a procedure has been performed on it which will 95% of the time return a range containing the true value. But it may happen that, owing to error in the measuring instruments, the experimental procedure returns a range [-0.5, -0.1], where it is physically impossible for the parameter to be less than zero. A Bayesian cheerfully says that since the prior probability of this range was effectively 0%, the posterior probability remains effectively 0%, and goes on to say that the real value of the parameter is probably quite close to zero. With a prior probability distribution over plausible values of the parameter, this remaining uncertainty can be quantified. A frequentist, in contrast, only goes on saying that the procedure performed would

work 95% of the time, and insists that there is nothing more to be said than this. It is nonsense to treat a fixed parameter as a random variable and assign probabilities to it; either the fixed parameter has value X or it does not.

If we are *decision* theorists, we can resolve this philosophical impasse by pointing a gun to the frequentist's head and saying, "Does the value of the fixed parameter lie in the range [-0.5, -0.1]? Respond yes or no. If you get it wrong or say any other word I'll blow your head off." The frequentist shrieks "No!" We then perform the experimental procedure again, and it returns a range of [0.01, 0.3]. We point the gun at the frequentist's head and say, "Does the value lie in this range?" The frequentist shrieks, "Yes!" And then we put the gun away, apologize extensively, and say: "You know the sort of belief that you used to make that decision? *That's* what a Bayesian calls by the name, 'probability'."

If you look at this reply closely, it says that *decision* theory requires any mathematical object describing *belief* to cash out to a scalar quantity, so that we can plug comparative degrees of belief into the expected utility formula. Mathematicians have devised Dempster-Shafer theory, long-run frequencies, and other interesting mathematical objects - but when there's a gun pointed at your head, you need something that cashes out to what decision theorists (and Bayesian statisticians) call a *probability.* If someone should invent an improvement on the expected utility formula that accepts some other kind of belief-object, and this improved decision rule produces better results, then perhaps decision theorists will abandon probabilities. But until then, decision theorists need some way to describe ignorance that permits choice under uncertainty, and our best current method is to cash out our ignorance as a real number between 0 and 1.

This is the Dutch Book argument for Bayesian probability (Ramsey 1931). If your uncertainty behaves in a way that violates Bayesian axioms, an exploiter can present you with a set of bets that you are guaranteed to lose.

The Dutch Book argument applies no less to your uncertainty about whether 678 * 987 equals 669186 or 669168. If you offered a truly committed frequentist only a small sum of money, perhaps he would sniff and say, "Either the result equals 669186 or it does not." But if you made him choose between the gambles G1 and G2, where G1 involves being shot if the value is 669186 and G2 involves being shot unless a fair coin turns up four successive heads, I think a sensible bounded rationalist would choose G1.[30] By requiring choices on many such gambles, we could demonstrate that the chooser assigns credences that behave much like probabilities, and that the probability he assigns is within epsilon of 50%.

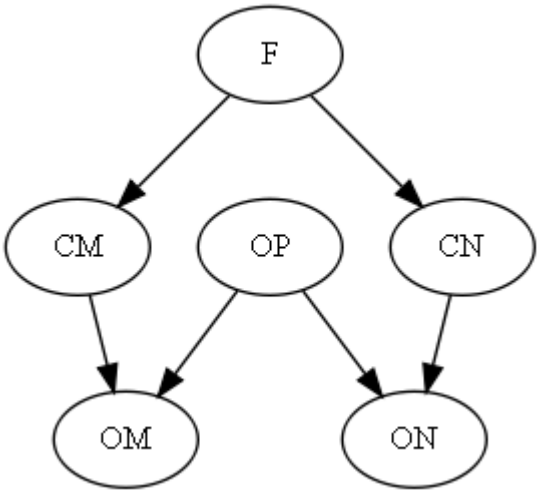
[30] Incidentally, I will flip a coin to determine which possible output I will cite in G1, only after writing the footnoted sentence and this footnote. If the false value happens to come up in the coin flip, then that will detract somewhat from the moral force of the illustration. Nonetheless I say that a sensible bounded rationalist, having no other information, should prefer G1 to G2.

Since I wish to devise a formalism for timeless *decision* diagrams, I presently see no alternative but to represent my ignorance of a deterministic computation's output as a probability distribution that can combine with other probabilities and ultimately plug into an expected utility formula.

Note that is important to distinguish between the notion of a *computation* and the notion of an *algorithm.* An "algorithm", as programmers speak of it, is a template for computations. The output of an algorithm may vary with its inputs, or with parameters of the algorithm. "Multiplication" is an algorithm. "Multiply by three" is an algorithm. "Multiply by X" is an algorithm with a parameter X. Take the algorithm "Multiply by X", set X to 987, and input 678: The result is a fully specified computation, 678 * 987, with a deterministic progress and a single fixed output. A computation can be regarded as an algorithm with no inputs and no parameters, but not all algorithms are computations.

An underlying assumption of this paper is that the same computation always has the same output. All jokes aside, humanity has never yet discovered any place in our universe where 2 + 2 = 5 - not even in Berkeley, California. If "computation" is said where "algorithm" is meant, paradox could result; for the same algorithm may have different outputs given different inputs or parameters.

So how would a causal diagram represent two spacelike separated calculators implementing the same computation? I can presently see only one way to do this that matches the observed facts, lets us make prudent choices under uncertainty, and obeys the underlying assumptions in causal diagrams:



F = f1(u1) p(u1)
CM = f2(F)
CN = f3(F)
OP = f4(u4) p(u4)
OM = f5(OP, CM)
ON = f6(OP, CN)

Figure 9:

Here F stands for the factory, located perhaps in Taiwan, which produced calculators CM and CN at Mongolia and Neptune (explaining their physically correlated state at the start of the problem). OP is a latent node[31] that stands for our uncertainty about the deterministic output of the abstract computation 678 * 987 - the "Platonic output" - and the outputs OM and ON at Mongolia and Neptune are the outputs which flash on the actual calculator screen.

[31] A latent node in a causal diagram is a variable which is not directly observed. Any suggestion that two correlated variables are linked by an unseen confounding factor hypothesizes a latent cause.

Why is it necessary to have a node for OP, distinct from F? Because this diagram is intended to faithfully compute probabilities and independences in the scenario where:

(a) We physically inspect the complete initial state of both calculators;
(b) We remain uncertain which symbols shall flash upon each of the two screens;
and yet
(c) We expect the uncertain flashing symbols at OM and ON to correlate.

If we delete the node OP and its arcs from Diagram D, then inspecting both CM and CN should screen off OM from ON, rendering them probabilistically independent. (The same also holds of deleting the node OP and inspecting F.) If we delete OP, we necessarily have that P(OM,ON|CM,CN) = P(OM|CM,CN)*P(ON|CM,CN). This does not correspond to the choices we would make under uncertainty. We would assign a probability of 50% to P(OM=669186|CM,CN) and also assign a probability of 50% to P(ON=669186|CM,CN) yet not assign a probability of 25% to P(OM=669186,ON=669186|CM,CN).

Which is to say: Suppose you have previously observed both calculators to implement the same multiplication, you trust both calculators to work correctly on the physical level (no cosmic ray strikes on transistors), and you have heard from a trustworthy source that 678 * 987 equals either 669186 or 669168. You might eagerly pay $1 for a gamble that wins $10 if the calculator at Mongolia shows 669186, or with equal eagerness pay $1 for a gamble that wins $10 if the calculator at Neptune shows 669168. Yet you would not pay 10 cents for a gamble that wins $100 if the Mongolian calculator shows 669186 and the Neptunian calculator shows 669168. Contrariwise, you would happily offer $2 for a gamble that wins $2.10 if the Mongolian calculator shows 669186 *or* the Neptunian calculator shows 669168. It's free money.

If we deal in rolling dice and sealed envelopes, rather than uncertainty about *computations,* then knowing completely the physical initial conditions at Mongolia and Neptune rules out any lingering information between our conditional probability distributions over uncertain outcomes at Mongolia and Neptune. Uncertainty about computation differs from uncertainty about dice, in that completely observing the physical initial conditions screens off any remaining uncertainty about dice[32], while it does not screen off uncertainty about the outputs of computations. The presence of the node OP in the causal diagram is intended to make the causal diagram faithfully represent this property of our ignorance.

[32] When I say that the uncertainty is "screened off", I don't necessarily mean that we can always compute the observed result of the die roll. I mean that no external event, if we witness it, can give us any *further* information about what to expect from our local die roll. Quantum physics complicates this situation considerably, but as best I understand contemporary physics, it is still generally true that if you start out by *completely* observing an observable variable, then outside observations should tell you no *further* information - quantum or otherwise - about it.

I emphasize that if we were *logically omniscient,* knowing every logical implication of our current beliefs, we would never experience any uncertainty about the result of calculations. A logically omniscient agent, conditioning on a complete initial state, would thereby screen off *all* expected information from outside events. I regard probabilistic uncertainty about computations as a way to manage our lack of logical omniscience. Uncertainty about computation is uncertainty about the logical implications of beliefs we already possess. As boundedly rational agents, we do not always have enough computing power to know what we believe.

OP is represented as a latent node, unobserved and unobservable. We can only determine the value of OP by observing some other variable to which OP has an arc. For example, if we have a hand calculator CH whose output OH is also linked to OP, then observing the value OH can tell us the value of OP, and hence OM and ON. Likewise, observing the symbols that flash on the calculator screen at OM would also tell us the product of 678 * 987, from which we could infer the symbols that will flash on the calculator screen at ON. This does seem to be how human beings reason, and more importantly, the reasoning works well to describe the physical world. After determining OP, by whatever means, we have independence of any *remaining* uncertainty that may arise about the outputs at OM and ON - say, due to a stray radiation strike on the calculator circuitry.

I suggest that we should represent *all* abstract computational outputs as latent nodes, since any attempt to infer the outcome of an abstract computation works by observing the output of some physical process believed to correlate with that computation. This holds whether the physical process is a calculator, a mental calculation implemented in axons and dendrites, or a pencil and paper that scratches out the axioms of Peano arithmetic.

I also emphasize that, when I insert the Platonic output of a computation as a latent node in a causal diagram, I am not making a philosophical claim about computations having Platonic existence. I am just trying to produce a good *approximation* of reality that is faithful in its predictions and useful in its advice. Physics informs us that beneath our macroscopic dreams lie the facts of electrons and protons, fermions and bosons. If you want objective reality, look at Feynman diagrams, not decision diagrams[33]. Our fundamental physics invokes no such fundamental object as a "calculator", yet a causal diagram containing a node labeled "calculator" can still produce good predictions about the behavior of macroscopic experience.

The causal diagram D, if you try to read it directly, seems to say that the Platonic result of a calculation is a cause that reaches out and modifes our physical world. We are not just wondering about pure math, after all; we are trying to predict

[33] So far as I am concerned, probability distributions are also a sort of useful approximation bearing no objective reality (until demonstrated otherwise). Physics does invoke something like a distribution over a space of possible outcomes, but the values are complex amplitudes, not scalar probabilities.

which symbols shall flash on the physical screen of a physical calculator. Doesn't this require the Platonic output of 678 * 987 to somehow modify the physical world, acting as a peer to other physical causes? I would caution against trying to read the causal diagram in this way. Rather, I would say that our *uncertainty* about computation exhibits *causelike behavior* in that our uncertainty obeys the causelike operations of dependence, independence, inference, screening off, etc. This does not mean there is a little Platonic calculation floating out in space somewhere. There are two different kinds of uncertainty interacting in diagram D: The first is uncertainty about physical states, and the second is uncertainty about logical implications. The first is uncertainty about possible worlds and the second is uncertainty about impossible possible worlds (Cresswell 1970).

This multiply uncertain representation seems to adequately describe ignorance, inference, decisions, dependence, independence, screening off, and it cashes out to a probability distribution that doesn't make absurd predictions about the physical universe. It is also pretty much the obvious way to insert a single computational uncertainty into a Bayesian network.

I make no specification in this paper as to how to compute prior probabilities over uncertain computations. As we will see, this question is orthogonal to the decision algorithm in this paper; so for our purposes, and for the moment, "ask a human mathematician" will do.

For my second augmentation, yielding timeless decision diagrams, I propose that an agent represent *its own decision* as the output of an abstract computation which describes the agent's decision process.

I will first defend a general need for a representation that includes more than a simple blank spot as the cause of our own decisions, on grounds of *a priori* reasonableness and representational accuracy.

Decisions, and specifically human decisions, are neither acausal nor uncaused. We routinely attempt to predict the decisions of other humans, both in cases where prediction seems hard (Is she likely to sleep with me? Is he likely to stay with me if I sleep with him?) and easy (Will this starving person in the desert choose to accept a glass of water and a steak?) Some evolutionary theorists hypothesize that the adaptive task of manipulating our fellow primates (and, by implication, correctly modeling and predicting fellow primates) was the most important selection pressure driving the increase of hominid intelligence and the rise of *Homo sapiens.* The Machiavellian Hypothesis is especially interesting because out-predicting your conspecifics is a Red Queen's Race, an open-ended demand for increasing intelligence in each successive generation, rather than a single task like learning to chip handaxes. This may help to explain a rise in hominid cranial capacity that stretched over 5 million years.

We model the minds, and the decisions, and the acts of other human beings. We model these decisions as depending on environmental variables; someone is more likely to choose to bend down and pick up a bill on the street, if the bill is $50 rather than $1. We could not do this successfully, even to a first approximation in the easiest cases, if the decisions of other minds were uncaused. We achieve our successful predictions through insight into other minds, understanding cognitive details; someone who sees a dollar bill on the street values it, with a greater value for $50 than $1, weighs other factors such as the need to stride on to work, and decides whether or not to pick it up. Indeed, the whole field of decision theory revolves around arguments about how other minds do or should arrive at their decisions, based on the complex interaction of desires, beliefs, and environmental contingencies. The mind is not a sealed black box.

Why emphasize this? Because the standard formalism for causal diagrams seems to suggest that a manipulation, an act of *do(xi)*, is *uncaused.* To arrive at the formula for p(y|x^i) - sometimes also written p(y|do(xi)) - we are to sever the variable Xi from all its parents PAi; we eliminate the conditional probability p(xi| pai) from the distribution; we replace the calculation Xi := fi(pai, ui) with Xi := xi. Since the variable X has no parents, doesn't that make it uncaused? Actually, we couldn't possibly read the graph in this way, since Xi represents not our *decision* to manipulate X, but the manipulated variable itself. E.g., if we make the sidewalk wet as an experimental manipulation, the variable Xi would represent the wetness of the sidewalk, not our decision to make the sidewalk wet. Presumably, asking for a distribution given do(Xi=wet) means that the wetness is caused by our experimental manipulation, not that Xi becomes uncaused.

Pearl (1993) suggests this alternate representation of an experimentally manipulable causal diagram:

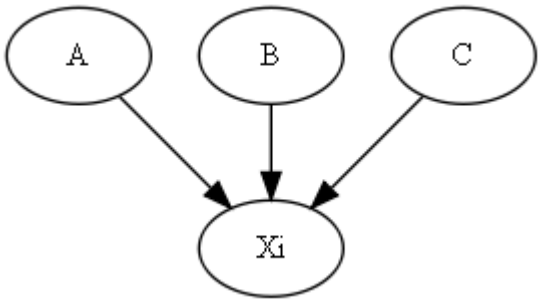


Figure 10:

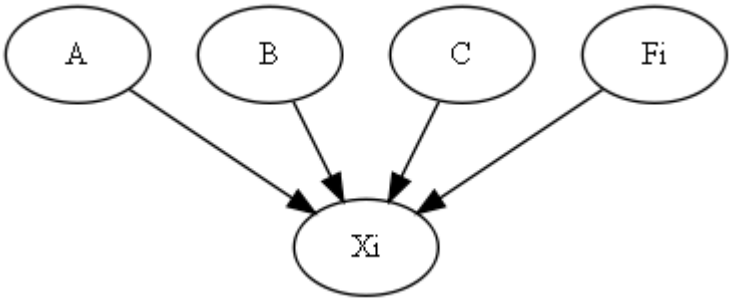


Figure 11:

Xi := fi(A, B, C, ui)

Fi := {idle, do(xi)}
Xi := I(fi, A, B, C, ui)

p(xi | pa'i) = { P(xi|pai) if Fi = idle
0 if Fi = do(x'i) and xi != x'i

1 if Fi = do(x'i) and xi = x'i

Here the function I(fi, pai, ui) = fi(pai, ui). The possible values of Fi include an "idle" function which equals fi in G, and functions do(xi) for the possible xi in X. These latter functions are independent of PAi. Thus, the function Xi = I(fi, pai, ui) exhibits *context-specific independence* from A, B, C given that Fi takes on the specific value do(xi); but if Fi takes on the *idle* value, then Xi will depend on A, B, C.[34] Fi is meant to represent our act, or our decision, and Fi=idle represents the decision to do nothing. *Providing that Fi is itself without parent causes* in the diagram G', PG' (y|Fi=do(xi)) = PG(y|x^i). As for attempting to read off implied independences from the augmented graph, we must first modify our algorithm to take account of context-specific independences (Boutilier et al. 1996); but when this is done, the same set of independences will be predicted.

The formulation in G', though harder to write, is attractive because it has no special semantics for p(y|xi); instead the semantics for do(xi) emerge as a special case of conditioning on Fi. However, the variable Fi itself still seems to be "without cause", that is, without parents in the diagram - does this mean that our decisions are acausal? I would again caution against reading the diagram in this way. The variable SEASON is without cause in Diagram D, but this does not mean that seasons are causeless. In the real world seasons arise from the long orbit of the Earth about the Sun, the axial tilt of our spinning world, the absorption and emission of heat by deep lakes and buried ground. These causes are not beyond physics, nor even physically unusual. As best as science has ever been able to determine, the changing of the seasons obeys the laws of physics, indeed is produced by the laws of physics.

What then do we mean by showing the variable SEASON without parents in Diagram D? We mean simply that the variable SEASON obeys the Markov Condition relative to diagram D, so that we can find some way of writing:

SEASON = f1(u1) p(u1)
RAIN = f2(SEASON, u2) p(u2)
SPRINKLER = f3(SEASON, u3) p(u3)
WET = f4(RAIN, SEASON, u4) p(u4)
SLIPPERY = f5(WET, u5) p(u5)

such that the probability distributions over ui are independent: p(u1u2u3u4u5) = p(u1)p(u2)p(u3)p(u4)p(u5). We require that, whatever the background causes contributing to SEASON, and whatever the variance in those background causes contributing to variance in SEASON, these background causes do not affect, e.g., the slipperiness of the sidewalk, except through the mediating variable of the sidewalk's wetness. If the Earth's exact orbital distance from the Sun (which varies with the season) somehow affected the slipperiness of the sidewalk, we

[34] For an explanation of context-specific independence and some methods of exploiting CSI in Bayesian networks, see (Boutilier et al. 1996).

would find that the predicted independence p(SLIPPERY|WET) = p(SLIPPERY|WET,SEASON) did not hold. So the diagram D does not claim that SEASON is without cause, or that the changing season represents a discontinuity in the laws of physics. D claims that SEASON obeys the Markov Condition relative to D.

So too with our own decisions, if we represent them in the diagram as Fi. As best as science has currently been able to determine, there is no special physics invoked in human neurons (Tegmark 2000). Human minds obey the laws of physics, indeed arise from the laws of physics, and are continuous in Nature. Our *fundamental* physical models admit no Cartesian boundary between atoms within the skull and atoms without. According to our fundamental physics, all Nature is a single unified flow obeying mathematically simple low-level rules, including that fuzzily identified subsection of Nature which is the human species. This is such an astonishing revelation that it is no wonder the physicists had to break the news to humanity; most ancient philosophers guessed differently.

Providing that our decisions Fi obey the Markov condition relative to the other causes in the diagram, a causal diagram can correctly predict independences. *Providing that our decisions are not conditioned on other variables in the diagram,* the do-calculus can produce correct experimental predictions of joint probabilities. But in real life it is very difficult for human decisions to obey the Markov condition. We humans are adaptive creatures; we tend to automatically condition our decisions on every scrap of information available. Thus clinical researchers are well-advised to flip a fair coin, or use a pseudo-random algorithm, when deciding which experimental subjects to assign to the experimental group, and which to the control group.

What makes a coin fair? Not the long-run frequency of 50% heads; a rigged coin producing the sequence HTHTHTHT... also has this property. Not that the coin's landing is unpredictable *in principle;* a nearby physicist with sufficiently advanced software might be able to predict the coin's landing. But we assume that, if there are any predictable forces in the coin's background causes, these variables are *unrelated* to any experimental background causes of interest - they obey the Markov property relative to our causal diagram. This is what makes a coinflip a good way to *randomize* a clinical trial. The experiment is not actually being randomized. It is being Markovized. It is Markov-ness, *not* the elusive property of "randomness", that is the necessary condition for our statistics to work correctly.

Human decision is a poor way to "randomize" a clinical trial because the variance in human decisions does *not* reliably obey the Markov condition relative to background causes of interest. If we want to examine the experimental distribution for p(RAIN|do(WET)) to confirm the causal prediction that p(RAIN|do(WET)) = p(RAIN), we'd better flip a coin to decide when to pour water on the sidewalk. Otherwise, despite our best intentions, we may put off the experimental trial until that annoying rain stops.

A pseudo-random algorithm is a good way to Markovize a clinical trial, unless the same pseudo-random algorithm acting on the same randseed was used to "randomize" a previous clinical trial on the same set of patients. Perhaps one might protest, saying: "The 'pseudo-random' algorithm is actually deterministic, and the background propensities of the patients to sickness are fixed parameters. What if these two deterministic parameters should by happenstance possess an objective correlation?" But exactly the same objection applies to a series of coinflips, once the results are affixed to paper. No reputable medical journal would reject a clinical trial of Progenitorivox on the basis that the pseudo-random algorithm used was "not really genuinely fundamentally random". And no reputable medical journal would accept a clinical trial of Progenitorivox based on a series of "really genuinely fundamentally random" coinflips that had previously been used to administer a clinical trial of Dismalax to the same set of patients.

Given that, in reality itself, our decisions are not uncaused, it is possible that reality may throw at us some challenge in which we can only triumph by modeling our decisions as causal. Indeed, every clinical trial in medicine is a challenge of this kind - modeling human decisions as causal is what tells us that coinflips are superior to human free will for Markovizing a clinical trial.

So that is the justification for placing an agent's decision as a node in the diagram, and moreover, connecting parent causes to the node, permitting us to model the complex causes of decisions - even our own decisions. That is the way reality *actually* works, all considerations of decision theory aside. I intend to show that we can faithfully represent this aspect of reality without producing absurd decisions - that we can choose wisely *even if* we correctly model reality.

I further propose to model decisions as the outputs of an *abstract* computational process. What sort of physically realizable challenge could demand such a diagram? I have previously proposed that a bounded rationalist needs to model abstract computations as latent nodes in a causal diagram, whenever the same abstract computation has more than one physical instantiation. For example, two calculators each set to compute 678 * 987. So we would need to model decisions as the output of an abstract computation, whenever this abstract computation has more than one physical instantiation.

The AI researcher Hans Moravec, in his book *Mind Children* (Moravec 1988), suggested that human beings might someday upload themselves from brains to computers, once computers were sufficiently powerful to simulate human minds. For example, nanomachines (a la Drexler 1986, Drexler 1992) might swim up to a neuron, scan its full cellular state in as much detail as possible, and then install molecular-scale mechanisms in and around the neuron which replaced the internal biological machinery of the cell with molecular-scale nanomachinery. After this operation had been repeated on each neuron in the brain, the entire

causal machinery of the brain would operate in a fashion subject to deliberate human intervention; and when the process was complete, we could read out the state of the entire brain and transfer it to an external computer. As Moravec observed, the patient could theoretically remain awake throughout the entire procedure. Moravec called this "uploading". (See also "The Story of a Brain" ?.)

Leaving aside the question of whether future humans will ever undergo such a procedure, uploading is one of the most fascinating *thought experiments* ever invented. On any electronic mailing list it is possible to generate a long and interminable argument just by raising the question of whether your uploaded self is "really you" or "just a copy". Fortunately that question is wholly orthogonal to this essay. I only need to raise, as a thought experiment, the possibility of an agent whose decision corresponds to the output of an abstract computation with more than one physical instantiation.

Human beings run on a naturally evolved computer, the brain, which sadly lacks such conveniences as a USB 2.0 port and a way to dump state to an external recording device. The brain also contains mechanisms which are subject to thermal fluctuations. To the extent that thermal fluctuations play roles in cognition, an uploaded brain could use strong pseudo-random algorithms. If the pseudo-random algorithms have the same long-run frequencies and do not correlate to other cognitive variables, I would expect cognition to operate essentially the same as before. I therefore propose that we imagine a world in which neurons work the same way as now, except that thermal uncertainties have been replaced by pseudo-random algorithms, and neurons can report their exact states to an external device. If so, brains would be both *precisely copyable* and *precisely reproducible,* making it possible for the same cognitive computation to have more than one physical instantiation. We would also need some way of precisely recording sensory inputs, perhaps a simulated environment *a la* The Matrix (Wachowski and Wachowski 1999), to obtain reproducibility of the agent-environmental interaction.

Exact reproducibility is a strong requirement which I will later relax. Generally in the real world we do not need to run *exact* simulations in order to guess at the decisions of other minds - though our guesses fall short of perfect prediction. However, I find that thought experiments involving *exactly* reproducible computations can greatly clarify those underlying principles which I think apply to decision problems in general. If any readers have strong philosophical objections to the notion of reproducible human cognition, I ask that you substitute a decision agent belonging to a species of agents who exist on deterministic, copyable substrate. If even this is too much, then I would suggest trying to follow the general chain of argument until I relax the assumption of exact reproducibility.

The notion of uploading, or more specifically the notion of cognition with copyable data and reproducible process, provides a *mechanism* for a *physical realization* of Newcomb's Paradox.

Let Andy be an uploaded human, or let Andy be a decision agent belonging to a species of agents who exist on copyable substrate with reproducible process. At the start of our experiment, we place Andy in a reproducible environment. At the end of the experiment, we carry out this procedure: First, we play a recording which (truthfully) informs Andy that we have already taken our irrevocable action with respect to placing or not placing $1,000,000 in Box B; and this recording asks Andy to select either box B or both boxes. Andy can take box contents with him when he leaves the reproducible environment (i.e., Andy finds money in his external bank account, corresponding to the amounts in any boxes taken, after leaving the Matrix). Or perhaps Andy ordinarily lives in a reproducible environment and we do not need to specify any special Matrix. Regardless we assume that some act of Andy's (e.g., pressing a button marked "only B") terminates the experiment, in that afterward Andy can no longer take a different set of boxes.

In the middle of the experiment, we copy Andy and his environment, and then simulate Andy and his environment, using precisely the same recording to inform the simulated Andy that Box B has already been filled or emptied. If all elements in the reproduction work properly, the simulated Andy will reproduce perfectly the Andy who makes the actual decision between aB and aAB, perfectly predicting Andy's action. We then fill or empty box B according to the decision of the simulated Andy.

This thought experiment preserves the temporal condition that causal decision theorists have traditionally used to argue for the dominance of choosing both boxes. At the time Andy makes his decision, the box is already filled or empty, and temporal precedence prevents Andy's *local physical instantiation* from having any causal effect whatsoever upon box B. Nonetheless, choosing both boxes seems less wise than before, once we specify the mechanism by which the Predictor predicts. Barring cosmic ray strikes on transistors, it is as impossible for the Predictor to predict incorrectly, as it is impossible for a calculator computing 678 * 987 in Mongolia to return a different result from the calculator at Neptune.

For those readers who are open to the possibility that uploading is not only physically possible, but also pragmatically doable using some combination of future nanotechnology and future neuroscience, the realization of Newcomb's Problem right here in our real world is not out of the question. I regard this as a strong counterargument to those philosophers who argue that Newcomb's Problem is logically impossible.

Suppose that Andy presents himself for the experiment at 7AM, is copied immediately after, and then makes his decision at 8AM. I argue that an external observer who thinks in causal diagrams should represent Andy's experience as follows:

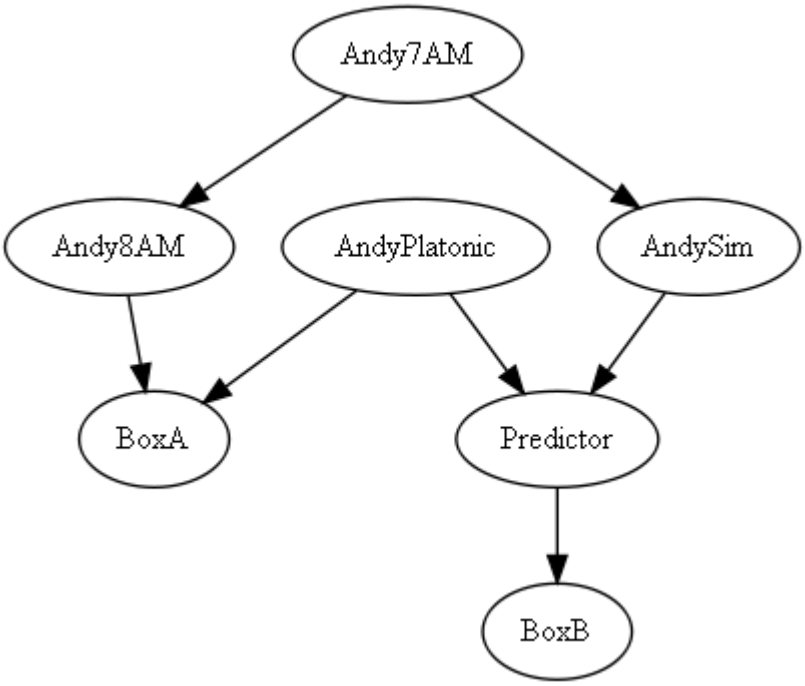


Figure 12:

As external observers we may lack the Predictor's mental power (or computing faculties) to fully simulate Andy and his reproducible environment - even if we have the ability to fully scrutinize Andy's initial condition at Andy7AM. Nonetheless, as external observers, we expect Andy8AM to correlate with AndySim, just as we expect calculators set to compute 678* 987 to return the same answers at Mongolia and Neptune. We do not expect observing the common cause Andy7AM to screen off Andy8AM from AndySim. We can organize this aspect of our uncertainty by representing the decisions of both Andy8AM and AndySim as connected to the latent node AndyPlatonic. We can then (correctly) infer the behavior of Andy8AM from AndySim and vice versa.

A classical causal decision theorist, acting as an external observer to Andy's dilemma, would also infer the behavior of Andy8AM from AndySim and vice versa - treating them as correlated because of their common cause, Andy7AM. (I have not seen the question of "screening off" raised.) Causal decision theorists do not regard themselves as being obligated to model *other* minds' actions as acausal. Let Bob be a causal decision theorist who witnesses a thousand games and observes the Predictor to always predict correctly. When Bob sees the next player choose only box B, Bob has no trouble predicting that box B will contain a million dollars.

The singularity in causal decision theory arises when Bob enters the game for himself, and must evaluate the expected utilities of his own possible actions. Consider Bob evaluating the expected utility of taking only box B, for which Bob computes p(B0|a^B) and p(B$|a^B). Bob reasons as follows: "The Predictor has already made his move; since I am a causal decision theorist, the Predictor's move is to leave B empty. Therefore if I take only box B, I receive nothing." That is, Bob evaluates p(B0|a^B) ~ 1 and p(B$|a^B) as ~ 0 - unless the Predictor has made a mistake; but at any rate p(B0) and p(B$) can bear no relation to Bob's own action. This probabilistic independence follows from Bob's model after he

deletes all parent causes of Bob8AM - Bob treats his own decision as acausal, for that is the prescription of causal decision theory.

But mark this: First, the causal decision theorist now models the expected consequence of his own actions using a causal graph which differs from the graph that successfully predicted the outcome of the Predictor's last thousand games. Does this not violate the way of science? Is this not an inelegance in the mathematics? If we treat causal diagrams as attempts to represent reality, which of these two diagrams is nearer the truth? Why does Bob think he is a special case?

Second, Bob evaluates the consequence of the action a_B, and asserts p(B$| a^_B) ~ 0, by visualizing *a visibly inconsistent world* in which BobSim and Bob8AM return *different outputs* even though they implement *the same abstract computation.* This is not a possible world. It is not even an impossible possible world, as impossible possible worlds are usually defined. The purpose of reasoning over impossible possible worlds is to manage a lack of logical omniscience (Lipman 1998) by permitting us to entertain possibilities that *may* be logically impossible but which we do not yet *know* to be logically impossible. For so long as we do not know Fermat's Last Theorem to be true, we can reason coherently about a possibly impossible possible world where Fermat's Last Theorem is false. *After* we prove FLT, then imagining ~FLT leads to *visibly* inconsistent mathematics from which we can readily prove a contradiction; and from a logical contradiction one may prove anything. The world in which Bob_Sim and Bob_8AM output different answers for the same abstract computation is not a possibly impossible possible world, but a definitely impossible possible world. Furthermore, the inconsistency is visible to Bob at the time he imagines this definitely impossible possible world.

I therefore suggest that, howsoever Bob models his situation, he should use a model in which there is never a visible logical inconsistency; that is, Bob should never visualize a possible world in which the same abstract computation produces different results on different (faithful, reliable) instantiations. Bob should never visualize that 678 * 987 is 669186 in one place and 669168 in another. One model which has this property is a timeless decision diagram. I have already drawn one timeless decision diagram, for Andy's Newcomb experience; it is diagram D that represents our uncertainty about Andy's decision, produced by Andy's cognition, as uncertainty about the output of an abstract computation that is multiply instantiated.

I emphasize again that using timeless decision diagrams to analyze Newcomblike problems and obtain *probabilities* over Newcomblike outcomes does not commit one to following a timeless decision algorithm. I emphasize this because philosophy recognizes a much larger component of *de gustibus non disputandum* in decision than in probability - it is simpler to argue beliefs than to argue acts. If someone chooses a 30% probability of winning a vanilla ice cream

cone over a 60% probability of winning a chocolate ice cream cone, perhaps the person simply doesn't like chocolate. It may also be that the person does like chocolate more than vanilla, and that the person has some incorrect factual belief which leads him to choose the wrong gamble; but this is hard to demonstrate. In contrast, someone who examines a vanilla ice cream cone and comes to the conclusion that it is chocolate, or someone who believes the sky to be green, or someone who believes that 2 + 2 = 3, has arrived to the wrong answer on a question of fact. Since a timeless decision *diagram* makes no direct prescription for acts, and of itself assigns only *probabilities*, it is that much less arguable - unless you find an algorithm that assigns better-calibrated probabilities.

The timeless decision diagram for Newcomb's Problem, considered as a prescription only over probabilities, is as in figure 12.

The diagram reads the same way for an outside observer or for Andy himself. If I am uncertain of Andy's decision - that is, the output of Andy's decision process, the value of the latent variable AndyPlatonic - whether I am Andy or I am an outside observer - then I am uncertain of the contents of box B. If I assign probabilities over Andy's possible decisions (whether I am Andy making a rough advance guess at his own future decision, or I am an outside observer), and I assign a 60% probability to Andy choosing only box B, then I assign a 60% probability to box B containing a million dollars. Considering my probability assessment as a measure over possibly impossible possible worlds, then I do not assign any measure to definitely impossible possible worlds that contain a logical inconsistency visible to me. Using standard methods for computing counterfactuals over the value of the variable AndyPlatonic, I believe that if the output of Andy's decision system were aB, then AndySim would choose aB, box B would contain a million dollars, and Andy8AM would leave behind box A. And if the output of Andy's decision system were aAB, then box B would be empty and Andy8AM would take both boxes. This all holds whether or not I am Andy - I use the same representation, believe the same beliefs about reality, whether I find myself inside or outside the system.

Here my analysis temporarily stays, and does not go beyond describing Andy's beliefs, because I have not yet presented a timeless decision algorithm.

Suppose the Predictor does not run an *exact* simulation of Andy. Is it conceivable that one may produce a faithful prediction of a computation without running that exact computation?

Suppose Gauss is in primary school and his teacher, as a punishment, sets him to add up all the numbers between 1 and 100. Immediately he knows that the output of this computation will be 5050; yet he did not bother to add 2 to 1, then add 3 to the result, then add 4 to the result, as the teacher intended him to do. Had he done so, the result - barring an error in his calculations - would have been 5050. A fast computation may faithfully simulate a slow computation.

Imagine that the Predictor wants to produce a good prediction of Andy (say, to an accuracy of one error in a thousand games) while expending *as little computing power as possible.* Perhaps that is the object of the Predictor's game, to arrive at veridical answers *efficiently,* using less computing power than would be required to simulate every neuron in Andy's brain. (What's the fun in merely running simulations and winning every time, after all?) If the Predictor is right 999 times out of 1000, that is surely temptation enough to choose only box B - though it makes the temptation less clear.

How is it possible that the Predictor can predict Andy without simulating him exactly? For that matter, how can we ourselves predict other minds without simulating them exactly? Suppose that Andy_8AM - "the real Andy" - finds himself in an environment with green-painted walls. And suppose that Andy_Sim finds himself in an environment with blue-painted walls. We would nonetheless *expect* - not prove, but probabilistically *expect* - that Andy_Sim and Andy_8AM come to the same conclusion. The Predictor might run a million alternate simulations of Andy in rooms with slightly different-colored walls, all colors *except* green, and find that 999 out of 1000 Andys decide to take only box B. If so, the Predictor might predict with 99.9% confidence that the real Andy, finding himself in a room with green walls, will decide to take only box B.

The color of the wall is not *relevant* to Andy's decision - presuming, needless to say, that Andy does not know which color of the wall tokens the "real Andy". Otherwise the Andys in non-green rooms and the Andy in the green room might behave very differently; the slight difference in sensory input would produce a large difference in their cognition. But if Andy has no such knowledge - if Andy doesn't know that green is the special color - then we can expect the *specific* color of the room not to influence Andy's decision in any significant way, even if Andy knows in a purely abstract way that the color of the room matters somehow. The Andy in a red room thinks, "Oh my gosh! The color of the room is red! I'd better condition my thoughts on this somehow... well, since it's red, I'll choose only box B." The Andy in a blue room thinks, "Oh my gosh! The color of the room is blue! I'd better condition my thoughts on this somehow... well, since it's blue, I'll choose only box B." If we're trying to simulate Andy on the cheap, we can *abstract out* the color of the room from our simulation of Andy, since the computation will probably carry on the same way regardless, and arrive to more or less the same result.

Now it may be that Andy is in such an unstable state that any random perturbation to Andy's brain or his environment, even a few neurons, has the potential to flip his decision. If so the Predictor might find that 70% of the simulated Andys decided one way, and 30% another, depending on tiny perturbations. But to the extent that Andy chooses rationally and for good reasons, we do not expect him to condition his decision on irrelevant factors such as the exact temperature of the room in degrees Kelvin or the exact illumination

in candlepower. Most descriptions of Newcomblike problems do not specify the wall color, the room temperature, or the illumination, as weighty arguments. If a philosopher Phil goes to all the trouble of arguing that tiny perturbations might influence Andy's decision and therefore the Predictor cannot predict correctly, Phil is probably so strongly opinionated about decision theory and Newcomblike problems that the Predictor would have no trouble predicting *him.*

If Andy doesn't know that the color of the room is significant, or if Andy doesn't start out knowing that the Predictor produces Its predictions through simulation, all the less reason to expect the color of the room to influence his thoughts. The Predictor may be able to abstract out entirely that part of the question, when It imagines a simplified version of Andy for the purpose of predicting Andy without simulating him. Indeed, in all the philosophical discussions of Newcomb's Problem, I have never once heard someone direct attention to the color of the walls in the room - we don't think it an important thought of the agent.

Perhaps the Predictor tries to predict Andy in much the same way that, e.g., you or I would predict the trajectory of other cars on the street without modeling the cars and their drivers in atomic detail. The Predictor, being superintelligent, may possess a brain embracing millions or billions of times the computing power of a human brain, and better designed to boot - say, for example, avoiding the biases described in Kahneman, Slovic and Tversky (1982). Yet the Predictor is so very intelligent that It does not *need* to use a billion times human computing power to solve the puzzle of Andy, just as we do not need to add up all the numbers between 1 and 100 to know the answer. We do not know in detail how the Predictor predicts, and perhaps Its mind and methods are beyond human comprehension. We just know that the Predictor wins the game 999 times out of 1000.

I do not think this would be so implausible a predictive accuracy to find in real life, if a Predictor came to this planet from afar, or if a superintelligence was produced locally (say as the outcome of recursive self-improvement in an Artificial Intelligence) and humanity survived the aftermath. I don't expect to find myself faced with a choice between two boxes any time soon, but I don't think that the scenario is physically impossible. If the humanity of a thousand years hence really wished to do this thing, we could probably do it - for tradition's sake, perhaps. I would be skeptical, but not beyond convincing, if I heard reports of a modern-day human being who could converse with someone for an hour and then predict their response on Newcomb's Problem with 90% accuracy. People do seem to have strong opinions about Newcomb's Problem and I don't think those strong opinions are produced by tiny unpredictable thermal perturbations. Again I regard this as a counterargument to those philosophers who argue that Newcomb's Problem is a logical impossibility.

How can *efficient* prediction - the prediction of a mind's behavior without simulating it neuron by neuron - be taken into account in a causal diagram?

Bayesian networks seem to me poorly suited for representing uncertainty about mathematical proofs. If A implies B implies C implies D, then knowing A proves D and thereby screens off all further uncertainty about D. Bayesian networks are efficient for representing probabilistic mechanisms. Bayesian networks are useful when, if A causes B causes C causes D, then knowing C screens off D from B, but knowing A does not screen off D from B. Mixing uncertainty about mathematical proof and uncertainty about physical mechanisms *efficiently* is innovation beyond the scope of this essay. Nonetheless, our uncertainty about mathematical proofs has a definite structure. If A implies B, then it would be foolish to assign less probability to B than to A. If A implies B and ~A implies ~B, then A <=> B, p(A) = p(B) and we may as well treat them as the same latent node in a causal diagram.

If the Predictor uses an efficient representation of Andy that *provably* returns the same answer as Andy - for example, by abstracting out subcomputations that provably have no effect on the final answer - then for any output produced by Andy_Platonic, it follows deductively that the Predictor's computation produces the same output, even if the Predictor's computation executes in less time than Andy himself. It is then a knowable logical contradiction for the Andy-computation to choose a_B and the Predictor's computation to predict a_AB, and we should not visualize a world in which this known contradiction obtains.

If the Predictor is using a probabilistic prediction of Andy (but an algorithm with excellent resolution; say, no more than 1 wrong answer out of 1000), this complicates the question of how to represent our uncertainty about the respective computations. But note that probabilistic prediction is no stranger to formal mathematics, the most obvious example being primality testing. The Rabin-Miller probabilistic test for primeness (Rabin 1980) is guaranteed to pass a composite number for at most 1/4 of the possible bases. If N independent tests are performed on a composite number, using N randomly selected bases, then the probability that the composite number passes each test is $1/4^N$ or less.

Suppose the Predictor uses a very strong but probabilistic algorithm. If I am an outside observer, then on witnessing Andy choose only box B, I make a strong inference about the contents of box B; or if I see that box B is full, I make a strong inference about Andy's decision. If I represent Andy_Platonic and Predictor_Simulation as different latent nodes, I can't possibly represent them as unconnected; this would require probabilistic independence, and there would then be no way for an observer to infer box B's contents from witnessing Andy's decision or vice versa.

I think that probably the best pragmatic way to deal with probabilistic prediction, for the purpose of Newcomb's Problem, is to draw a directed arrow from the latent node representing Andy's computation to a non-latent node representing the Predictor's simulation/prediction, with a conditional probability p(Predictor| Andy) or a mechanism f_Predictor(Andy, u_Predictor). We would only have

cause to represent the Predictor's computation as a latent node, if this computation itself had more than one physical instantiation of interest to us. Another argument is that the Predictor's simulation *probably* reflects Andy's computation, and whether or not this error occurs is a discoverable fact about the state of the world - the particular approximation that the Predictor chooses to run. A pragmatic argument for directing the arrow is that if we changed Andy's computation (for example, by substituting one value for another in the parameter of the underlying algorithm), then the Predictor would change Its simulation; but if the Predictor changed its simulation then the behavior of Andy would not follow suit in lock-step.

I regard this reasoning as somewhat ad-hoc, and I think the underlying problem is using Bayesian networks for a purpose (representing uncertainty about related mathematical propositions) to which Bayesian networks are not obviously suited. But to divorce decision theory from causal networks is a project beyond the ambition of this present essay.

For the purpose of this essay, when I wish to speak of a probabilistic simulation of a computation, I will draw a directed arrow from the node representing the computation to a node representing a probabilistic prediction of that computation. Usually I will choose to analyze thought experiments with multiple faithful instantiations of the same computation, or a perfect simulation guaranteed to return the same answer, because this simplifies the reasoning considerably. I do not believe that, in any case discussed here, probabilism changes the advice of TDT if the probabilities approach 1 or 0. I view this as a desirable property of a decision theory. The difference between 10^{-100} and 0 should only rarely change our preferences over actions, unless the decision problem is one of split hairs.

The principle that drives my choice of theory is to update probabilities appropriately. We should avoid visualizing worlds known to be logically impossible; we should similarly decrease the probability of worlds that are known to be probably logically impossible, or that are logically known to be improbable. I have proposed, as a pragmatic solution, to draw a directed arrow from a computation to a probabilistic simulation of that computation. If someone drives this theory to failure, in the sense that it ends up visualizing a knowably inconsistent world or attaching high probability to a knowably improbable world, it will be necessary to junk that solution and search for a better way of managing uncertainty.

Solomon's Problem (see page 5)

The second most popular Newcomblike problem, after Newcomb's Problem itself, is a variant known as Solomon's Problem. As you may recall from page 5, the formulation of Solomon's Problem we are using is chewing-gum throat-abscess problem.

Chewing gum has a curative effect on throat abscesses. Natural selection has produced in people susceptible to throat cancer a tendency to chew gum. It turns out that a single gene, CGTA, causes people to chew gum and makes them susceptible to throat cancer. As this causal diagram requires, conditioning on the gene CGTA renders gum-chewing and throat abscesses statistically independent. We are given these observations:

	Chew gum	Don't chew gum
CGTA present:	89% die	99% die
CGTA absent:	8% die	11% die

If we do not know yet whether we carry the gene CGTA, should we decide to chew gum? If we do find ourselves deciding to chew gum, we will then be forced to conclude, from that evidence, that we probably bear the CGTA gene. But chewing gum cannot possibly *cause* us to bear the CGTA gene, and gum has been directly demonstrated to ameliorate throat abscesses.

Is there any conceivable need here to represent our own decision as the output of an abstract decision process? There is no Predictor here, no uploaded humans, no exact or approximate simulation of our decision algorithm. Solomon's Problem is usually classified as a Newcomblike problem in the philosophical literature; is it a timeless decision problem?

Before I answer this question, I wish to pose the following dilemma with respect to Solomon's Problem: How would this situation ever occur in real life if the population were made up of causal decision theorists? In a population composed of causal theorists, or evidential theorists with tickling, *everyone* would chew gum just as soon as the statistics on CGTA had been published. In this case, chewing gum provides no evidence at all about whether you have the gene CGTA - even from the perspective of an outside observer. If only some people have heard about the research, then there is a new variable, "Read the Research", and conditioning on the observation RTR=rtr+, we find that chewing gum no longer correlates with CGTA. Everyone who has heard about the research, whether they bear the gene CGTA or not, chews gum.

To avoid this breakdown of the underlying hypothesis, let us postulate that most people are instinctively evidential decision theorists without tickling. We postulate, for the sake of thought experiment, a world in which humanity evolved with the heuristic-and-bias of evidential decision theory. Around 50,000 years ago in this alternate universe, the first statisticians began drawing crude but accurate tables of clinical outcomes on cave walls, and people instinctively began to avoid chewing gum in order to convince themselves they did not bear the CGTA gene. Because of the damage this decision caused to bearers of the CGTA gene (which for some reason was not simply selected out of the gene pool; maybe the CGTA gene also made its bearers sexy), a mutation rapidly

came to the fore which turned CGTA bearers (and for some reason, only CGTA bearers) into a different kind of decision theorist.

Now we have already specified that most people, in this subjunctive world, are CGTA-negative evidential decision theorists. We have been told the output of their decision process; they decide to avoid gum. But now we come to the decision of a person named Louie. Louie bears a mutation that makes him a new kind of decision theorist... a *more powerful* decision theorist. Shunned by ordinary decision theorists who do not understand their powers, the new breed of decision theorists band together to form a crimefighting group known as the X-Theorists... Ahem. Excuse me. Louie bears a mutation that makes him not-an-evidential decision theorist. Louie knows that CGTA-negative decision theorists choose not to chew gum, and that people who don't chew gum usually don't get throat abscesses. Louie knows that gum helps prevent throat abscesses. Louie correctly explains this correlation by supposing that population members who are CGTA-negative are evidential decision theorists, and evidential theorists choose not to chew gum, and CGTA-negative individuals are less susceptible to throat abscesses. Louie knows that CGTA-positive decision theorists implement a different algorithm which causes them to decide to chew gum.

Aha! Why "Aha!", you ask? Whether Louie believes himself to be CGTA-positive or CGTA-negative, or whether Louie starts out uncertain of this, Louie must model a world that contains potential copies of his own decision process. The other individuals are not exact copies of Louie. But we have been proposing a hypothesis under which all people who implement *this* algorithm decide this way, and all people who implement *that* algorithm decide that other way. It seems that, whatever the different inputs and parameters for separate instantiations of this algorithm, it makes no difference to the output (on the appropriate level of abstraction). One CGTA-positive individual reasons, "To maximize the expected utility of the person that is Mary, should Mary chew gum?" And the output is, "Mary should chew gum." And another reasons: "To maximize the expected utility of the person that is Norman, should Norman chew gum?" And the output is, "Norman should chew gum." If in a sense these two computations return the same answer, it is because in a sense they are the same computation. We need only substitute "I" for "Mary" and "Norman" to see this. Perhaps, for a species of intelligent agents sufficiently exact in their evaluation of expected utility, the two computations would *provably* return the 'same' answer.

Not yet knowing the decision of Mary, but knowing that her computation bore so close a resemblance to that of Norman, we would infer Mary's decision from Norman's or vice versa. And we would make this inference even after inspecting both their initial states, if we remained uncertain of the outcome. Therefore I propose to model the similarity between these two individuals as stemming from a shared abstract computation.

From this entry point, I introduce the following timeless decision diagram of (one possible mechanism for) Solomon's Problem.

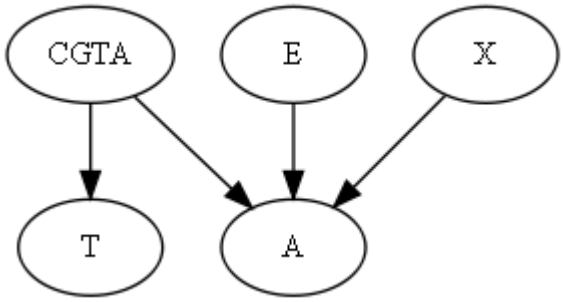


Figure 13:

Node CGTA takes on the values cgta- or cgta+, standing for CGTA-negative and CGTA-positive individuals. CGTA directly affects (has an arrow into) the variable T, which represents throat abscesses. CGTA also affects a variable A, which represents an individual's decision whether to chew gum. Also showing arrows into A are the nodes E and X, representing evidential decision theorists and X-Theorists. E is a latent node whose value is the decision output by the abstract computation E, which implements an evidential decision algorithm without tickling. X is the abstract computation that determines the shared behavior of X-Theorists. The function f_A(CGTA, E, X) exhibits a context-specific independence; if CGTA takes on the value cgta-, then A's remaining dependency is only on E, not on X. If CGTA takes on the value cgta+, then A depends on X but not on E. This context-specific independence represents the proposition that CGTA-negative individuals implement the E computation and CGTA-positive individuals implement the X computation. We know that E takes on the value "avoid gum" and X takes on the value "chew gum".

A latent node in a timeless diagram represents the fixed output of a fixed computation. If Louie is uncertain of which computation he implements, the diagram represents this uncertainty using a context-specific independence: a variable which indicates uncertainty about which algorithm describes Louie. In this case the gating variable is CGTA, which also affects susceptibility to throat abscesses. But CGTA has no arrows into the abstract algorithms, E and X. Whether an individual bears the CGTA gene does not affect the fixed output of a deterministic computation - it only affects *which* abstract computation that individual's physical makeup instantiates.

Either Louie or an outside observer, who believes that this diagram describes Louie's situation, believes the following:

- Given that Louie decides to chew gum, he probably has the CGTA gene and will probably develop a throat abscess.
- Given that Louie decides not to chew gum, he probably does not have the CGTA gene and will probably not develop a throat abscess.
- If people who implemented computation E decided to chew gum, they would develop fewer throat abscesses.
- If the output of abstract computation X were "don't chew gum", people who implemented X would develop more throat abscesses.

- The probability that an individual carries the CGTA gene is unaffected by the outputs of X and E, considered as abstract computations.

Again, as I have not yet introduced a timeless decision algorithm, the analysis does not yet continue to prescribe a rational decision by Louie. But note that, even considered intuitively, Louie's beliefs under these circumstances drain all intuitive force from the argument that one should choose not to chew gum. Roughly, the naive evidential theorist thinks: "If only I had chosen not to chew gum; then I would probably not have the CGTA gene!" Someone using a timeless decision graph thinks: "If my decision (and the decision of all people sufficiently similar to me that the outputs of our decision algorithms correlate) were to avoid gum, then the whole population would avoid gum, and avoiding gum wouldn't be evidence about the CGTA gene. Also I'd be more likely to get a throat abscess."

And note that again, this change in thinking amounts to dispelling a definitely impossible possible world - refusing to evaluate the attractiveness of an imaginary world that contains a visible logical inconsistency. If you think you may have the CGTA gene, then thinking "If only I instead chose to avoid gum - then I would probably not have the CGTA gene!" visualizes a world in which *your* decision alters in this way, while the decisions of *other* CGTA-positive individuals remain constant. If you all implement the same abstract computation X, this introduces a visible logical inconsistency: The fixed computation X has one output in your case, and a different output everywhere else.

Similarly with the classical causal decision theorist in Newcomb's problem, except that now it is the causal decision theorist who evaluates the attractiveness of a visibly inconsistent possible world. The causal decision theorist says, "The Predictor has already run its simulation and made its move, so even if I were to choose only box B, it would still be empty." Though this may seem more rational than the thought of the evidential decision theorist, it nonetheless amounts to visualizing an inconsistent world where AndySim and Andy8AM make different decisions even though they implement the same abstract computation.

14: The timeless decision procedure

The timeless decision procedure evaluates expected utility conditional upon the output of an abstract decision computation - the very same computation that is currently executing as a timeless decision procedure - and returns that output such that the universe will possess maximum expected utility, conditional upon the abstract computation returning that output.

I delay the formal presentation of a timeless decision algorithm because of some significant extra steps I wish to add (related to Jeffrey (1983)'s proposal of ratifiability), which are best justified by walking through a Newcomblike problem to show why they are needed. But at the core is a procedure which, in every faithful instantiation of the same computation, evaluates which *abstract* output of

that computation results in the best attainable state of the universe, and returns that output. Before adding additional complexities, I wish to justify this critical innovation from first principles.

Informally, Newcomb's Problem is treated as specified in figure 12.

The abstract computation Andy_Platonic with instantiations at both Andy_8AM and Andy_Sim computes the expected utility of the universe, if the abstract computation Andy_Platonic returns the output a_AB or alternatively a_B. Since this computation computes the universe to have higher utility if its output is a_B, the computation outputs a_B (in both its instantiations).

Andy still chooses a_B if Andy believes that the Predictor does not execute an exact Andy_Sim, but rather executes a computation such that Andy_8AM =: a_B => Andy_Sim =: a_B and Andy_8AM =: a_AB => Andy_Sim =: a_AB. Here X =: Y denotes "computation X produces output Y" and "X => Y" denotes implication, X implies Y. In this circumstance the two computations may be treated as the same latent node, since our probability assignments over outputs are necessarily equal.

Andy outputs the same decision if Andy believes the Predictor's exact physical state is very probably but not certainly such that the mathematical relation between computations holds. This can be represented by a gating variable and a context-specific indepedence, selecting between possible computations the Predictor might implement. Given that Andy's utility is linear in monetary reward, and that Andy's probability assignment to the gating variable shows a significant probability that the Predictor predicts using a computation whose output correlates with Andy's, Andy will still output a_B.

Informally, the timeless decision diagram D models the content of box B as determined by the output of the agent's *abstract* decision computation. Thus a timeless decision computation, when it executes, outputs the action a_B which takes only box B - outputting this in both instantiations. The timeless decision agent walks off with the full million.

15: Change and determination: A timeless view of choice.

Let us specify an exact belief set - a probability distribution, causal diagram, or timeless diagram of a problem. Let us specify an exact evidential, causal, or timeless decision algorithm. Then the output of this decision computation is fixed. Suppose our background beliefs describe Newcomb's Problem. Choosing a_AB is the fixed output of a causal decision computation; choosing a_B is the fixed output of an evidential decision computation; choosing a_B is the fixed output of a timeless decision computation.

I carefully said that a causal decision agent visualizes a *knowable* logical inconsistency when he computes the probability p(B_$|a^_B) ~ 0. A timeless

decision agent also visualizes a logical inconsistency when she imagines what the world would look like if her decision computation were to output a_AB - because a timeless computation *actually* outputs a_B.

A timeless agent visualizes many logically inconsistent worlds in the course of deciding. Every imagined decision, except one, means visualizing a logically inconsistent world. But if the timeless agent does not yet know her own decision, she does not know *which* visualized worlds are logically inconsistent. Even if the timeless agent thinks she can guess her decision, she does not *know* her decision as a logical fact - not if she admits the tiniest possibility that thinking will change her answer. So I cannot claim that causal decision agents visualize impossible worlds, and timeless agents do not. Rather causal agents visualize knowably impossible worlds, and timeless agents visualize impossible worlds they do not know to be impossible.

An agent, in making choices, must visualize worlds in which a deterministic computation (the decision which is now progressing) returns an output other than the output it actually returns, though the agent does not yet *know* her own decision, nor know which outputs are logically impossible. Within this strange singularity is located nearly all the confusion in Newcomblike problems.

Evidential decision theory and causal decision theory respectively compute expected utility as follows:

u(o)p(o|a_i)
u(o)p(o|a^_i)

Placed side by side, we can see that any difference in the choice prescribed by evidential decision theory and causal decision theory, can stem *only* from different probability assignments over consequences. Evidential decision theory calculates one probable consequence, given the action a_i, while causal decision theory calculates another. So the dispute between evidential and causal decision theory is not in any sense a dispute over *ends,* or which goals to pursue - the dispute is *purely* over probability assignments. Can we say *de gustibus non est disputandum* about such a conflict?

If a dispute boils down to a testable hypothesis about the consequences of actions, surely resolving the dispute should be easy! We need only test alternative actions, observe consequences, and see which probability assignment best matches reality.

Unfortunately, evidential decision theory and causal decision theory are eternally unfalsifiable - and so is TDT. The dispute centers on the consequences of logically impossible actions, counterfactual worlds where a deterministic computation returns an output it does not actually return. In evidential decision theory, causal decision theory, and TDT, the observed consequences of the

action actually *performed* will confirm the prediction made for the performed action. The dispute is over the consequences of decisions *not* made.

Any agent's ability to make a decision, and the specific decision made, is determined by the agent's ability to visualize logically impossible counterfactuals. Moreover, the counterfactual is "What if my currently executing decision computation has an output other than the one it does?", when the output of the currently executing computation is not yet known. This is the confusing singularity at the heart of decision theory.

The difference between evidential, causal, and TDT rests on different prescriptions for visualizing *counterfactuals* - untestable counterfactuals on logical impossibilities.

An evidential decision theorist might argue as follows: "We cannot observe the impossible world that obtains if my decision computation has an output other than it does. But I can observe the consequences that occur to other individuals who make decisions different from mine - for example, the rate of throat abscesses in individuals who choose to chew gum - and that is just what my expected utility computation says it should be."

A timeless decision theorist might argue as follows: "The causal decision agent computes that even if he chooses a_B, then box B will still contain nothing. Let him just *try* choosing a_B, and see what happens. And let the evidential decision theorist *try* chewing gum, and let him observe what happens. Test out the timeless prescription, just one time for curiosity; and see whether the consequence is what TDT predicts or what your old algorithm calculated."

A causal decision theorist might argue as follows: "Let us try a test in which some force unknown to the Predictor reaches in from outside and presses the button that causes me to receive only box B. Then I shall have nothing, confirming my expectation. This is the only proper way to visualize the counterfactual, 'What if I chose only B instead?' If I really did try choosing a_B on 'just one time for curiosity', as you would have it, then I must predict a different set of consequences on that round of the problem than I do in all other rounds. But if an unknown outside force reached in and pressed the button 'take both boxes' for you, you would see that having both boxes is better than having only one."

An evidential agent (by supposition CGTA-negative) computes, as the expected consequence of avoiding gum, the observed throat-abscess rate of other (CGTA-negative) people who avoid gum. This prediction, the only prediction the evidential agent will ever test, is confirmed by the observed frequency of throat abscesses. Suppose that throat abscesses are uncomfortable but not fatal, and that each new day brings with an independent probability of developing a throat abscess for that day - each day is an independent data point. If the evidential

agent could be persuaded to just *try* chewing gum for a few months, the observed rate of throat abscesses would *falsify* the prediction used inside the evidential decision procedure as the expected consequence of deciding to chew gum. The observed rate would be the low rate of a CGTA-negative individual who chews gum, not the high rate of a CGTA-positive individual who chews gum.

A causal decision agent, to correctly predict the consequence even of the single action decided, must know in advance his own decision. Without knowing his own decision, the causal decision agent cannot correctly predict (in the course of decision-making) that the expected consequence of taking both boxes is $1000. If the Predictor has previously filled box B on 63 of 100 occasions, a causal agent might believe (in the course of making his decision) that choosing both boxes has a 63% probability of earning $1,001,000 - a prediction falsifiable by direct observation, for it deals with the decision actually made.[35] If the causal agent does not know his decision before making his decision, or if the causal agent truly believes that his action is acausal and independent of the Predictor's prediction, the causal agent might prefer to press a third button - a button which takes both boxes *and* makes a side bet of $100 that pays 5-for-1 if box B is full. We presume that this decision also is once-off and irrevocable; the three buttons are presented as a single decision. So we see that the causal agent, to choose wisely, must know his own decision in advance - he cannot just update afterward, on pain of stupidity.

If the causal agent *is* aware of his own decision in advance, then the causal agent will correctly predict $1000 as the consequence of taking both boxes, and this prediction will be confirmed by observing the consequence of the decision actually made. But if the causal agent tries taking only box B, just one time for curiosity, the causal agent must quickly change the predictions used - so that the causal agent now predicts that the consequence of taking both boxes is $1,001,000, and the consequence of taking only one box is $1,000,000.

Only the timeless decision agent can test predicted consequences in the intuitively obvious way, "Try it a different way and see what happens." If the timeless decision agent tries avoiding gum, or tries taking both boxes, the real-world outcome is the same consequence predicted as the timeless counterfactual of that action on similar problems.

Here is another sense in which TDT is superior to causal decision theory. Only the timeless decision procedure calculates internal predictions that are testable, in the traditional sense of testability as a scientific virtue. We do not let physicists quickly switch around their predictions (to match that of a rival theory, no less), if we inform them we intend to perform an unusual experiment.

[35] It is falsifiable in the sense that any single observation of an empty box provides significant Bayesian evidence for the hypothesis "Box B is empty if I take both boxes" over the hypothesis "Box B has a 63% chance of being full if I take both boxes". With repeated observations, the probability of the second hypothesis would become arbitrarily low relative to the first, regardless of prior odds.

How *should* we visualize unobservable, impossible, counterfactual worlds? We cannot test them by experience. How strange that these counterfactual dreams - unfalsifiable, empty of empirical content - determine our ability to determine our own futures! If two people wish to visualize different untestable counterfactuals, is there no recourse but to apply the rule of *de gustibus non est disputandum*? I have so far offered several arguments for visualizing counterfactuals the timeless way:

1) The counterfactual predictions used by timeless decision agents are directly testable any time the timeless decision agent pleases, because the timeless agent expects that trying the action 'just once for curiosity' will return the consequence expected of that action on any similar problem.
2) A timeless counterfactual is not *visibly* logically inconsistent, if the timeless agent does not yet know her decision, or if the timeless agent thinks there is even an infinitesimal chance that further thinking might change her mind.
3) A timeless agent uses the same diagram to describe herself as she would use to describe another agent in her situation; she does not treat herself as a special case.
4) If you visualize logically impossible counterfactuals the way that TDT prescribes, you will actually win on Newcomblike problems, rather than protesting the unreasonableness of the most rewarded decision.

Freedom and necessity

I have called it a logical impossibility that, on a well-defined decision problem, an agent with a well-defined algorithm should make any decision but the one she does. Yet to determine her future in accordance with her will, an agent must visualize logically impossible worlds - how the world would look if the agent made a different decision - not *knowing* these worlds to be impossible. The agent does not know her decision until she chooses, from among all the impossible worlds, the one world that seems to her most good. This world alone was always real, and all other worlds were impossible from the beginning, as the agent knows only after she has made her decision.

I have said that this strange singularity at the heart of decision theory is where the confusion lurks. Not least did I refer to that related debate, often associated with discussion of Newcomb, called *the problem of free will and determinism.* I expect that most of my readers will have already come to their own terms with this so-called problem. Nonetheless I wish to review it, because the central appeal of causal decision theory rests on human intuitions about *change*, *determination,* and *control.*

It seems to me that much confusion about free will can be summed up in the following causal diagram:

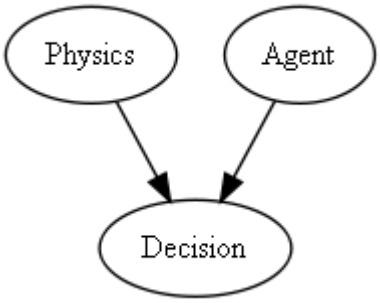


Figure 14:

Suppose our decisions are completely determined by physics - given complete knowledge of the past, our present choice is thereby determined: p(decision_i|PHYSICS) = 1 for one particular value of decision_i, and all decisions have p(decision_j) = 0. If so, then p(DECISION|PHYSICS) = p(DECISION|PHYSICS, AGENT). For if PHYSICS determines DECISION with certainty, then there is nothing left over to be determined by the variable AGENT, and the alleged causal link from AGENT to DECISION is extraneous. We have no influence at all over our own choices; they are determined wholly and entirely by physics. The feeling we have, of being in control of our own thoughts and actions, is but an illusion - it is really physics that is in control the whole time.

Before the invention of mathematical physics, a similar fear was expressed by earlier philosophers who asked if the future were already determined:

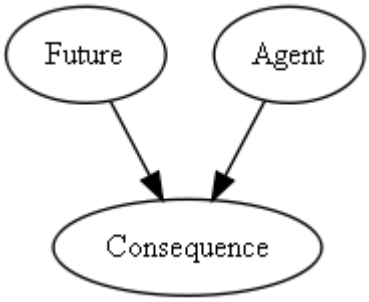


Figure 15:

If all the future is already recorded, a book unread but already written, then what use decision? Let the agent strive as he wills, and he will not alter the outcome. The agent has no part in determining the consequence of his decision. The consequence is copied down from the fixed book of the future, which was established irrespective of human deeds. If p(consequence_i|FUTURE) = 1, then there can be no further influence from AGENT; p(CONSEQUENCE|FUTURE) = p(CONSEQUENCE|FUTURE,AGENT).

What both diagrams have in common is that they place the agent outside Nature - outside physics, outside the future. And this is the classical error of Descartes, who sealed the mind on one side of an unalterable boundary, and the world upon the other. How few people ever learn *intimacy* with physics - intimacy enough to see human beings as existing *within* physics, not outside it? For this truth our physics tells us, so surprising that few accept the consequences: All reality is a single flow, one unified process obeying simple low-level mathematical rules, and we ourselves a continuous part of this flow, without interruption or boundary. That which is determined by humans, is of necessity determined by physics; for humans exist entirely within physics. If an outcome were not determined by physics, it could not possibly be determined by human choice.

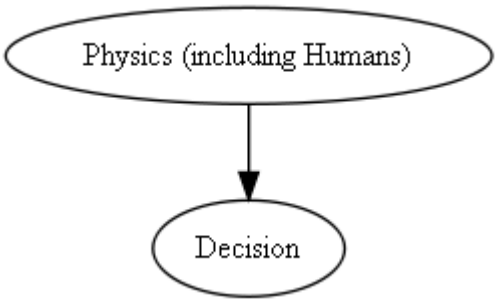


Figure 16:

But for most people who confront this question, "physics" is a strange and foreign discipline, learned briefly in college and then forgotten, or never learned at all; cryptic equations useful for solving word problems but not for constraining expectations of the real world, and certainly without human relevance. For the idea that humans are part of physics to make *intuitive* sense, we would have to understand our own psychology in such detail that it blended seamlessly into physics from below.

Psychology is a macroscopic regularity in physics, the way that aerodynamics is a macroscopic regularity of physics. Our excellent predictive models of airplanes may make no mention of individual "atoms", and yet our *fundamental* physics contains no *fundamental* elements corresponding to airflow or drag. This does not mean aerodynamics is incompatible with physics. The science of aerodynamics is how we humans manage our lack of logical omniscience, our inability to know the implications of our own beliefs about fundamental physics. We don't have enough computing power to calculate atomic physical models over entire airplanes. Yet if we look closely enough at an airplane, with a scanning tunneling microscope for example, we see that an airplane is indeed made of atoms. The causal rules invoked by the *science* of aerodynamics do not exist on a *fundamental* level within Nature. Aerodynamic laws do not reach in and do additional things to atoms that would not happen without the laws of aerodynamics as an additional clause within Nature. If we had enough computing power, we could produce accurate predictions without any science of aerodynamics - just pure fundamental physics.

Our science of aerodynamics is not just compatible with, but in a deep sense *mandated* by, our science of fundamental physics. If a non-atomic model[36] succeeds in delivering good empirical predictions of an airplane, this does not falsify our fundamental physics, but rather confirm it.

The map is not the territory. Nature is a single flow, one continuous piece. Any division between the science of psychology and the science of physics is a division in human knowledge, not a division that exists in things themselves. If you dare break up knowledge into academic fields, sooner or later the unreal boundaries will come back to bite. So long as psychology and physics *feel* like separate disciplines, then to say that physics determines choice *feels* like saying that psychology cannot determine choice. So long as electrons and desires *feel* like different things, to say that electrons play a causal role in choices *feels* like leaving less room for desires.

A similar error attends visualization of a future which, being already determined, leaves no room for human choice to affect the outcome.

Physicists, one finds, go about muttering such imprecations as "Space alone, and time alone, are doomed to fade away; and henceforth only a unity of the two

[36] E.g. a computer program none of whose data elements model individual atoms.

will maintain any semblance of reality." (Minkowski 1908) They tell us that there is no simultaneity, no *now* that enfolds the whole changing universe; *now* only exists locally, in *events*, which may come before or after one another, but never be said to happen at the same time. Students of relativity are told to imagine reality as a single four-dimensional crystal, spacetime, in which all events are embedded. Relativity was not the beginning of physics clashing with philosophy built on intuition; Laplace also disturbed the philosophers of his day, when Laplace spoke of, given an exact picture of the universe as it existed *now,* computing all future events. Special Relativity says that there is no *now,* but any spacelike-tilted slice through the timeless crystal - any space of apparent simultaneity - will do as well for Laplace's purpose, as any other. General Relativity requires that the *fundamental* equations of physics exhibit CPT symmetry: If you take an experimental record and reverse charge, parity, and the direction of time, all *fundamental* laws of physics inferred from the modified record must look *exactly* the same.[37]

In the ordinary human course of visualizing a counterfactual, we alter one variable in the past or present, and then extrapolate from there, forward in time. The physicists say poetically to imagine reality as a timeless crystal; so we imagine a static image of a crystal, static like a painting. We hold that crystal in our minds and visualize making a single change to it. And because we have imagined a crystal like a static painting, we see no way to extrapolate the change *forward* in time, as we customarily do with counterfactuals. Like imagining dabbing a single spot of paint onto the Mona Lisa, we imagine that only this one event changes, with no other events changing to match. And translating this static painting back into our ordinary understanding of time, we suppose that if an agent chooses differently, the future is the same for it; altering one event in the present or past would not alter the future.

This shows only that a static painting is a poor metaphor for reality.

Relativity's timeless crystal is not a static painting that exists unchanging *within* time, so that if you dab a spot of paint onto the painting at time T, nothing else has changed at time T+1. Rather, if you learn the physics that relates events within the crystal, this is all there is or ever was to time. That's the problem with priming our intuitions by visualizing a timeless crystal; we tend to interpret that as a static object embedded in higher-order time. We can see the painting, right there in our mind's eye, and it doesn't change. When we imagine dabbing a spot of paint onto the painting, nothing else changes, as we move the static painting forward in higher time.

[37] Then why do eggs break but not unbreak? No electrons in the egg behave differently whether we run the movie forward or backward; but the egg goes from an ordered state to a disordered state. Any observed macroscopic asymmetry of time must come from thermodynamics and the low-entropy boundary condition of our past. This includes the phenomenon of apparent quantum collapse, which arises from the thermodynamic asymmetry of decoherence.

So *visualizing* the future as a static painting causes your intuitions to return nonsensical answers about counterfactuals. You can't observe or test counterfactuals, so you should pick a rule for counterfactuals that yields rewarding outcomes when applied in decision theory. I do not see the benefit to an agent who believes that if a black hole had swallowed the entire Solar System in 1933, the Allies would still have won World War II. That is not how "future" events relate to "past" events within the crystal. To imagine that an agent had made a different choice, is disruption enough, for it violates the natural law which related the agent's choice to the agent's prior state. Why add further disruptions to tweak future events back into exactly the same place? You can imagine if you wish; *de counterfactus non est disputandum.* But what is the benefit to the agent, of visualizing counterfactuals in this way?

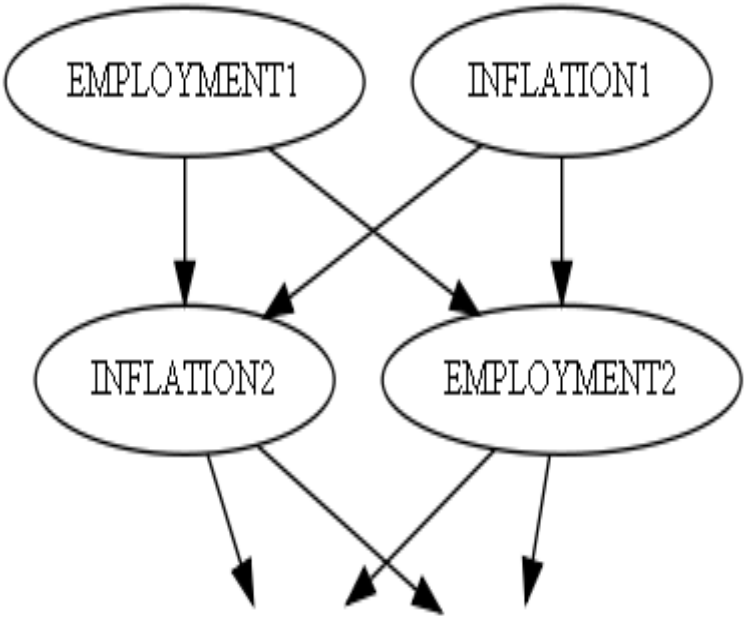
Intuition gone astray says that, if the future is already determined, our choices are effectless. I think that visualizing a static painting - not a timeless crystal containing time, but a painted future static within higher-order time - is the mental image that sends intuition astray.

We can imagine a world where outcomes really *are* determined in advance. An alien Author writes a novel, and then sets forth to re-enact this novel with living players. Behind the scenes are subtle mechanisms, intelligent machinery set in place to keep history on its track, irrespective of the decisions of the players. The Author has decreed World War II, and it will happen on schedule; if Hitler refuses his destiny, the machines will alter him back into schedule, or overwrite some other German's thoughts with dreams of grandeur. Even if the agents' decisions took on other values, the background machinery would tweak events back into place, copying down the outcome from the written book of the future.

What determines the Author's world? The background machinery that tweaks events back into place when they threaten to depart the already-written novel. But our world has no such background machinery, no robots working behind the scenes - not to my knowledge. Where is the mechanism by which an already-written future could determine the outcome regardless of our choices?

Yet if the future is determined, how could we change it?

Our intuitive notion of *change* comes from observing the same variable at different times. At 7:00 AM the egg is whole, then at 8:00 the same egg is broken; the egg has changed. We would write EGG_t=7 = egg_whole, EGG_t=8 = egg_broken. But this is itself a judgment of identity - to take the different variables EGG_t=7 and EGG_t=8, which may have different values, and lump the variables together in our minds by calling them the *same* egg. A causal diagram can express two interrelated variables, such as "Inflation rates influence employment; employment rates influence inflation" and yet still be a directed *acyclic* graph. We would write:



It may be the case that employment in 2005 influences inflation in 2005, and that inflation in 2005 influences employment in 2005 - but this only shows that our times are not split finely enough. We collapsed many separate events into the lump sum of 2005 - choices of employers to hire or fire, choices of shopkeepers to mark up or mark down.

If we have any two nodes A, B in a causal diagram, such that A causally affects B, and B causally affects A, this is more than just a problem with a formalism defined only for acyclic graphs. It means we have postulated two events, such that A lies in the future of B, and B lies in the future of A. Short of building a time machine - creating a closed timelike curve - this cannot happen.[38]

I do not argue that a formalism for causal diagrams prohibits circular causality; the appropriate response to such an argument is "So what?" Our choice of mathematical formalisms does not determine reality. If the formalism fails to fit reality it is the formalism that must give way. Importantly, physics appears to agree with mere intuition that time is not cyclic. An *event* has a single location in space and time. A particular egg at exactly 7:00AM may be considered an event. An egg as it changes over the course of hours, much less "eggs in general", is not an event. *Affecting* is a relationship between two events. It is forbidden - not merely by our formalism, but much more importantly by physics (once again, barring closed timelike curves) - for any two events A and B to be such that A is

[38] Many physicists believe that time machines are impossible, logically contradictory, absurd, and unimaginable, precisely because time machines allow circular causality; a theory that permits closed timelike curves is sometimes regarded as "pathological" on that account. Perhaps time machines *are* impossible, even for that very reason. I would even say that I thought it likely that the majority of physicists are right and time travel is impossible; if I were a physicist and had any right to an opinion. But we don't actually *know* that time travel is impossible. History teaches us that Nature cares very little for what we think is impossible, logically contradictory, absurd, and unimaginable. That only states how human brains think about causality; and Nature may have other ideas. If human intuitions have evolved in such a way that we cannot conceive of circular causality, this only shows that hunter-gatherers encountered no closed timelike curves. So I do not say that it is *knowably* impossible to have circular causality - only that circular causality has never been observed, and our fundamental physics makes it impossible in the absence of a time machine. When I write "physics forbids X", read, "our current model of physics (in the absence of time machines, which aren't involved in most real-world decision problems, and are probably impossible) forbids X". Should some person invent a time machine, this section of my essay will need to be revised.

affecting B and B is affecting A. If we conceive that employment affects inflation, and inflation affects employment, then we must have lumped together many different events under the name "employment" or "inflation".

What does it mean to *change* the future?

It is worth taking some time to analyze this confusion, which is built into the foundations of causal decision theory. Recall that we are told to take both boxes because this decision cannot *change* the contents of box B.

The future is as determined as the past. Why is it that philosophers are not equally bothered by the determinism of the past? Every decision any agent ever made, ended with some particular choice and no other; it became part of our fixed past. Today you ate cereal for breakfast. Your choice *could have been* something else, but it wasn't, and it never will be something else; your choice this morning is now part of the unalterable past. Why is your decision that lies in the fixed past, still said to be the outcome of free will? In what sense is the fixed past free? Even if we suppose that the future is not determined, how can we blame a murderer for choosing to kill his victims, when his decision lies in the past, and his decision-variable cannot possibly take on any value other than the one it had? How can we blame this past decision on the murderer, when the past is not free? We should really blame the decision on the past.

We may call the past and future "fixed", "determined", or "unalterable" - these are just poor metaphors which borrow the image of a painting remaining static in higher-order time. There is no higher-order time within which the future could "change"; there is no higher-order time within which the future could be said to be "fixed". There is no higher-order time within which the past could change; there is no higher-order time within which the past is fixed. The future *feels* like it can change; the past *feels* like it is fixed; these are *both* equally illusions.

If we consider a subsystem of a grand system, then we can imagine predicting the future of this subsystem *on the assumption* that the subsystem remains undisturbed by other, outside forces that also exist within the grand system. Call this the *future-in-isolation* of the subsystem. Given the exact current state of a subsystem as input, we suppose an extrapolating algorithm whose output is the computed *future-in-isolation* of the subsystem.

If an outside force perturbs the subsystem, we may compute that the subsystem now possesses a different future-in-isolation. It is important to recognize that a future-in-isolation is a property of a subsystem *at a particular time.* (Pretend for the moment that we deal with Newtonian mechanics, so the phrase "at a particular time" is meaningful.) Hence, the future-in-isolation of a subsystem may change from time to time, like an egg whole at 7AM and broken at 8AM, as outside forces perturb the subsystem.

The notion of changing a future-in-isolation, seems to me to encapsulate what goes on in the mind of a human who wishes to change the future. We look at the course of our lives and say to ourselves: "*If this goes on,* I shall not prosper; I shall not gain tenure; I shall never become a millionaire; I will never save the world..." So we set out to change the future *as we expect it, as we predict it;* we strive, time passes, and we find that we now compute a different future for ourselves - I will save the world after all! Have we not, then, changed the future? Our *prediction* has changed, from one time to another - and because the future is the referent of a prediction, it feels to us like the future itself has changed from one time to another. But this is mixing up the map with the territory.

Our notions of "changing" the future come - once again! - from considering ourselves as forces external to reality, external to physics, separated by an impenetrable Cartesian boundary from the rest of the universe. If so, by our acts upon the vast "subsystem" that is every part of reality except ourselves, we may change (from one time to another) the future-in-isolation of that tremendous subsystem. But there is a larger system, and the grand system's future does not "change". A box may appear to change mass, as we add and subtract toys, yet the universe as a whole always obeys conservation of energy. Indeed the future *cannot* "change", as an egg can change from whole to broken. Like the past, the future only ever takes on a single value. *Mirai wa itsumo tada hitotsu.*

Pearl's exposition of *causality* likewise divides the universe into subsystems. When we draw a causal diagram, it makes testable non-experimental predictions, and the same diagram also makes many different testable experimental predictions about the effect of interventions upon the system. This is a glorious virtue of a hypothesis. But the notion of *intervention,* upon which rests so much of the usefulness of causal diagrams, implies a grand universe divided into things inside the causal diagram, and things outside the causal diagram. A causal diagram of the *entire* universe, including all potential experimenters, would make only a single, non-experimental prediction. There would be no way to step outside the diagram to intervene.

I hold it a virtue of any decision theory that it should be compatible with a grand-system view, rather than *intrinsically* separating the universe into agent and outside. All else being equal, I prefer a representation which is continuous over the grand universe and marks no special boundary where the observer is located; as opposed to a representation which solidifies the Cartesian boundary between an observer-decider homunculus and the environment. One reason is epistemological conservationism, keeping your ontology as simple as possible. One reason is that we have seen what strange results come of modelling your own situation using a different hypothesis from the hypothesis that successfully predicted the outcome for every other agent who stood in your place. But the most important reason is that Cartesian thinking is factually untrue. There is not *in fact* an impenetrable Cartesian border between the agent and the outside. You need only drop an anvil onto your skull to feel the force of this argument, as the

anvil-matter smashes continuously through the brain-matter that is yourself thinking. All else being equal, I prefer a representation which describes the agent as a continuous part of a larger universe, simply because this representation is closer to being true.

Such a representation may be called *naturalistic* as contrasted to *Cartesian.* I am also fond of Ernest Nagel's beautiful term, "the view from nowhere" (Nagel 1989) Nagel meant it as an impossibility, but ever since I heard the term I have thought of it as the rationalist's *satori*. I seek to attain the view from nowhere, and using naturalistic representations is a step forward.

Gardner's Prime Newcomb Problem

Martin Gardner (1974) offers this refinement of Newcomb's Problem: Box B, now made transparent like box A, contains a piece of paper with a large integer written on it[39]. You do not know whether this number is prime or composite, and you have no calculator or any other means of primality testing. If this number proves to be prime, you will receive $1 million. The Predictor has chosen a prime number if and only if It predicts that you will take only box B. "Obviously," says Gardner, "you cannot by the act of will make the large number change from prime to composite or vice versa."

Control - the power attributed to acts of will - is the essence of the dispute between causal decision theory or evidential decision theory. Our act in Newcomb's Problem seems to have no way of *controlling* the fixed contents of box B. Therefore causal decision theorists argue it cannot possibly be reasonable to take only box B. Letting the content of box B depend on the primeness of a number makes it clear that the content of box B is utterly fixed and absolutely determined; though this is already given in the Newcomb's Problem specification. Interestingly, to show the *absolute* fixity of box B's content, Gardner would make the outcome depend on the output of an abstract computation - a computation which tests the primality of a given integer.

I agree with Gardner that there is no way to *change* or *modify* the primeness of a fixed number. The result of a primality test is a deterministic output of a fixed computation. Nothing we do can possibly change the primeness of a number.

So too, nothing we do can possibly change our own decisions.

This phrasing sounds rather less intuitive, does it not? When we imagine a decision, there are so many futures hanging temptingly before us, and we *could* pick any one of them. Even after making our decision (which has only one value and no other), we feel free to change our minds (although we don't), and we feel

[39] Technically one cannot write an integer on a piece of paper, as integers are abstract mathematical objects; but one can write a symbolic representation of an integer on a piece of paper.

that we could just as easily pick a different choice if we wanted to (but we don't want to).

It is the sense of infinite allowance in our decisions, of *controlling* the future, to which I now turn my attention. The heart of Newcomb's Paradox is the question of whether our choice *controls* the contents of box B. An intuitive sense of causable *change* enhances the feeling of being in control. An intuitive sense of *determinism*, of fixity, opposes the feeling of being in control.

But this is subsystem thinking, not grand-system thinking. "Control" is a two-place predicate, a relation between a controller subsystem and a controlled subsystem. If a subsystem has a fixed future in the sense that its future-in-isolation never changes, then it cannot be controlled. If a subsystem has a deterministic future, *not* considered in isolation, but just because the grand system of which it is part has deterministic dynamics, the subsystem may still be controllable by other subsystems.

What does it mean to "control" a subsystem? There is more to it than change. When an egg smashes into the ground, its state changing "whole" to "broken" (from one time to another), we do not say that the ground controlled the egg.

We speak even of "self-command", of getting a grip on oneself. Control(Mary, Mary) binds the two-place predicate to say that Mary is controlled *by herself*. If the subsystem is only interacting with itself, would not its future-in-isolation remain constant? Considered as an abstract property of the entire Mary subsystem, Mary's future-in-isolation would remain constant from one time to another. Yet Mary probably conceives of herself as altering her own future, because her prediction of her self's future changes when she engages in acts of self-control.

Change and determination

1. A causal decision theory is sometimes defined as a decision theory which makes use of inherently causal language. By this definition, TDT is typed as a causal decision theory. In the realm of statistics, causal language is held in low repute, although spirited defense by Judea Pearl and others has helped return causality to the mainstream. Previous statisticians considered causality as poorly defined or undefinable, and went to tremendous lengths to eliminate causal language. Even counterfactuals were preferred to the raw language of asymmetrical causality, since counterfactuals can be expressed as pure probability distributions p(A []-> B). A causal Bayesian network can *compute* a probability distribution or a counterfactual, but a causal network contains additional structure found in neither. Unlike a probability distribution or a counterfactual distribution, a causal network has asymmetrical links between nodes which explicitly represent asymmetrical causal relations. Thus the classical causal

> decision theory of Joyce (1999) is, from a statistician's perspective, not *irredeemably* contaminated by causal language. Classical causal decision theory only uses counterfactuals and does not explicitly represent asymmetrical causal links.

Technically, TDT can also be cast in strictly counterfactual form. But the chief difference between TDT and CDT rests on *which* probability distributions to assign over counterfactual outcomes. Therefore I have explicitly invoked causal networks, including explicitly represented asymmetrical causal links, in describing how timeless decision agents derive their probability distributions over counterfactuals.

I wish to keep the language of causality, including counterfactuals, while proposing that the language of *change* should be considered harmful. Just as previous statisticians tried to cast out causal language from statistics, I now wish to cast out the language of change from decision theory. I do not object to speaking of an object changing state from one time to another. I wish to cast out the language that speaks of *futures*, *outcomes,* or *consequences* being changed by decision or action.

What should fill the vacuum thus created? I propose that we should speak of *determining* the outcome. Does this seem like a mere matter of words? Then I propose that our concepts must be altered in such fashion, that we no longer find it counterintuitive to speak of a decision determining an outcome that is "already fixed". Let us take up the abhorred language of higher-order time, and say that the future is already determined. Determined by what? By the agent. The future is already written, and we are ourselves the writers. But, you reply, the agent's decision can change nothing in the grand system, for she herself is deterministic. There is the notion I wish to cast out from decision theory. I delete the harmful word *change,* and leave only the point that her decision *determines* the outcome - whether her decision is itself deterministic or not.

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