Nature's Possibilities and Expectations[1]

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Abstract

A flexible and commonsensical theory of causality can be based on the idea of Nature's evolving predictions. Nature witnesses the unfolding of events at levels of detail finer than that of any actual witness, and she makes predictions of future events that are never falsified. Although we seldom see events as Nature sees them, we often conjecture about Nature's predictions from regularities we do see, and we sometimes build these conjectures into our own reasoning and prediction. Mathematically, these conjectures concern possibilities and expectations in Nature's event tree.

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The regularities we witness in the world are often called "Nature's laws." Who is Nature? She is only a metaphor, but this metaphor can take different shapes in our imagination. Sometimes we think of Nature merely as a witness; she witnesses what has happened so far, and using her laws, she can predict something about what will happen next. When her laws are categorical, she predicts the future with certainty, when her laws are only probabilistic, she gives odds for what will happen. On other occasions, we fancy Nature as an actor: she makes things happen according to her laws. When the laws are probabilistic, she is the one who rolls the dice and then enforces the outcome.

In science, the metaphor is kept at a distance. It may inspire theory, but it has no place in the formulation of hypotheses and their empirical verification. So the shape of the metaphor does not matter; anything goes. In the philosophy of science, on the other hand, the difference between a passive and active Nature appears to be significant, especially when we try to understand causality and the closely related concept of objective probability. Making Nature an actor gives us a vivid sense of the reality of these ideas and preserves a good deal of their mystery. But in a philosophy of science in which Nature appears merely as a witness and predictor, the mystery (and excitement) of causality and objective probability seem to drain away; there is nothing there but prediction.

In *The Art of Causal Conjecture* (1996), I argued for a passive Nature and a predictive understanding of causality. Causal regularities, I argued, are regularities in the temporal unfolding of events. Objective probabilities arise when these regularities are less than uniform. In this article, I pick up this theme and try to place it more clearly in its historical and philosophical context.

I begin by reviewing the flexibility of event trees as a representation of causal structure. The concept of an event tree for Nature leaves us free to assert or deny that Nature witnesses causal regularities of a given form in a given domain. Competing mathematical representations of causal structure, inasmuch as they restrict us to particular kinds of event trees, do not have the same flexibility. A stochastic process, for example, is equivalent to an event tree that is supplied with a precise time scale and a full probability specification. We will look at some simple examples that illustrate how restrictive this is.

1 Dynamic Regularity in Nature

Causal relations are dynamic regularities—regularities Nature witnesses and predicts as events unfold. The branches in Nature's event tree represent the possibilities Nature foresees for the step-by-step evolution of her knowledge, and probabilities on these branches express her limited ability to predict the direction the evolution will take. Although they are subjective probabilities for Nature, we may think about them in much the way statisticians are accustomed to thinking about objective probabilities. They are based on Nature's past experience, and they will be played out in Nature's future experience. If Nature posted her probabilities as betting offers, she would at least break even, approximately, against any opponent. In particular, the frequency with which events happen in a sequence of trials singled out by an opponent would approximate Nature's average probability for those events.

Figure 1 shows how Nature might predict the behavior of Rick, a youngster at home alone on a summer afternoon. Since it has a probability on each branch, the *event* *tree* in this figure can also be called a *probability tree*. The probabilities are Nature's predictions for what will happen in each situation. At the beginning of the afternoon, Nature does not know for sure whether Rick will attend to his bicycle tire. But based on her experience observing him and similar youngsters in similar situations, she gives odds of 4 to 1 that he will.

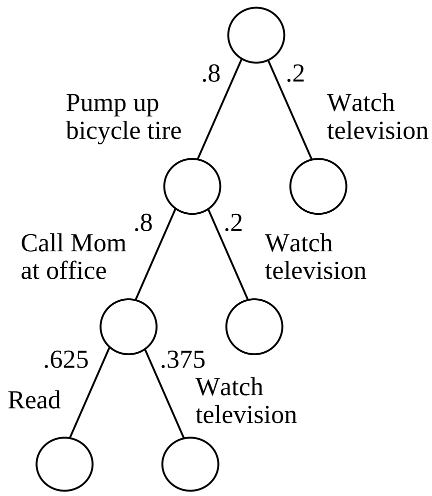

Figure 1 Nature's event tree for Rick's choices on a summer afternoon. The numbers are Nature's predictions (probabilities) for what will happen in each situation (circle).

In order to grasp fully the idea of Nature's evolving predictions, we must understand the refinement and simplification of event and probability trees (see Shafer 1996a, Chapter 13, and Shafer 1998). Nature's tree is presumably exceedingly complex, involving details that go far beyond our own current perceptions and preoccupations. Any tree we might draw is necessarily a simplification. But simplification is not necessarily falsification. Two probability trees, one more detailed than another, can both be accurate representations of Nature's limited ability to predict. Figure 2 illustrates the point; there the simpler tree on the right is consistent with the more refined tree on the left; both give the same initial probability for Rick's eventually reading (.8x.8x.625 = .4) and for his eventually watching television (.2 + .8x.2 + .8x.8x.375 = .6). We may call both "Nature's tree."

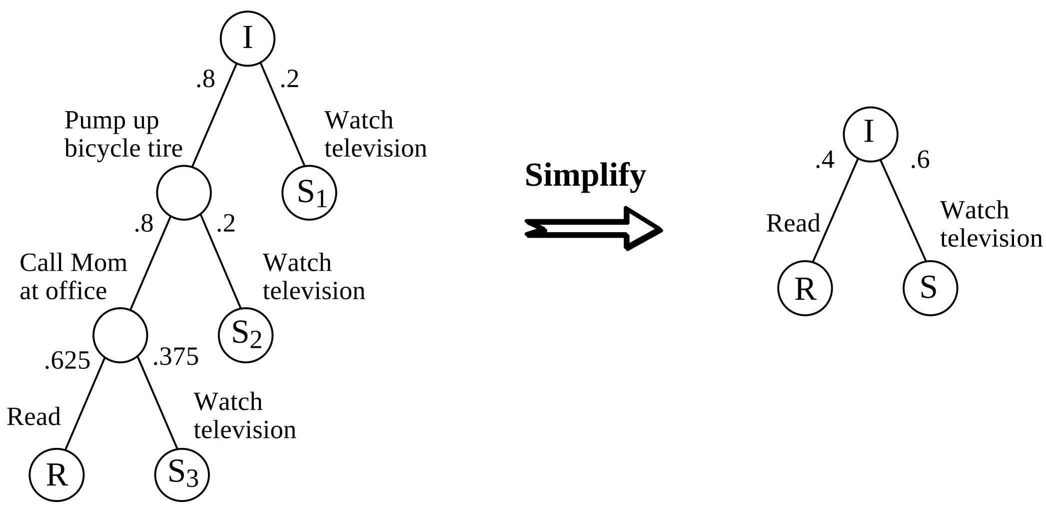

Figure 2 A simplification of Figure 1. The node S in the simplification has the same meaning as the collection $\{S_1,S_2,S_3\}$ of nodes in the refinement. Nature is in S precisely when she is either in S_1, in S_2, or in S_3.

In general, a node in an event tree represents an instantaneous event (the event that Rick starts watching television, for example) or, equivalently, a situation—the situation in which the instantaneous event has just occurred. Each instantaneous event in a valid simplification must also be represented in the tree it simplifies, possibly as the disjunction of several divergent instantaneous events. (Rick's starting to watch television is shown as a singe node in the simplified tree but as three distinct nodes in the refined tree.)

We need not suppose that the causal regularities Nature witnesses and predicts can always be expressed by probabilities, and consequently the refinement of a probability tree for Nature may produce an event tree for which we cannot put probabilities on every branch. For example, the tree on the right in Figure 2 might be valid even though there is no refinement of the kind illustrated on the left. In other words, Nature might assign a 60% probability to Rick eventually watching television without being able to make even probabilistic predictions about whether he will first pump up his bicycle tire or call his mother. This possibility is elaborated in Figure 3.

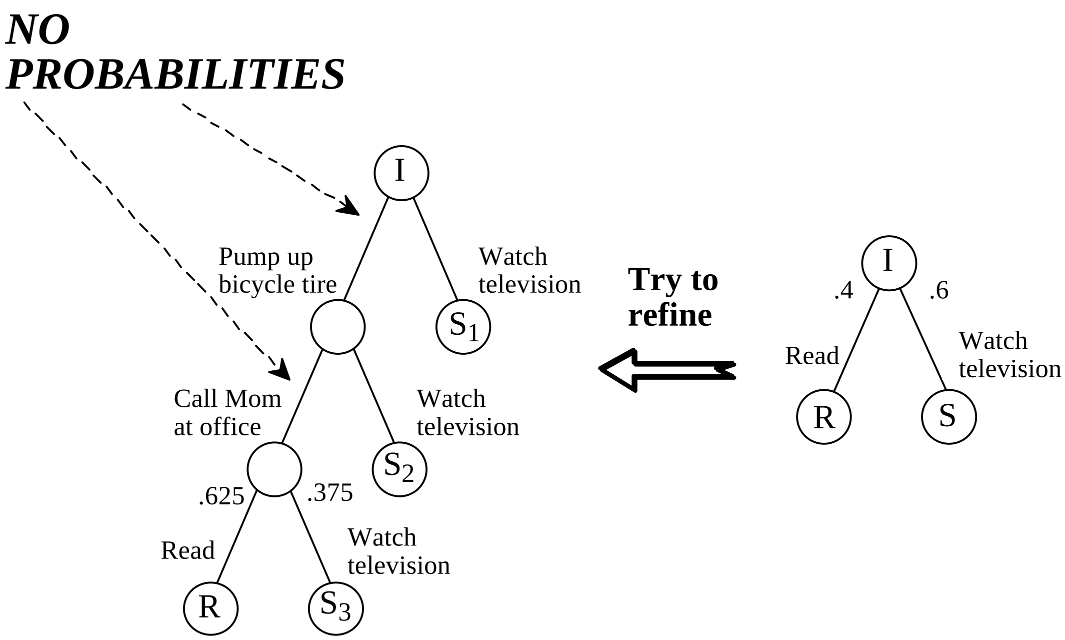

Figure 3 Here we suppose that the probability tree on the right is valid for Nature; in situations like I, Nature finds that Rick reads 40% of the time and watches television 60% of the time. These frequencies are stable through time. But this stability of frequencies is missing when Nature tries to predict whether Rick will pump up his bicycle tire or call his mother before

reading or watching television. In situations like these, Nature sees frequencies to vary over time and is unable to explain the variation.

2 Nature as an Idealization

The adjective “ideal” is often applied to simplifications of reality, as when we neglect friction in physics or the width of a line in geometry. When we simplify reality in this sense, we sacrifice precision in order to make a theory easier to understand and easier to use. The simplification is not precisely correct as a description of any real situation, although we can say that it represents the limit of correct descriptions of a sequence of real situations, in which the complications the simplification ignores are successively less important quantitatively.

The concept of Nature is also a limiting idealization, but in almost an opposite sense. There are regularities in the world that actual witnesses can and do see and that actual scientists can and do predict. Nature is the imagined limit as we consider witnesses and scientists who can see and predict more and more. This limit is a simplification of reality inasmuch as neglects limitations in the knowledge and computational capacity of real scientists. But the ideal structure of prediction that is imagined is not a simplification. On the contrary, it is the indefinitely complicated limit of a sequence of increasingly complicated structures of prediction.

This concept of Nature a limit of actual and potential witnesses provides a way of understanding the thought of Jacob Bernoulli, the seventeenth-century Swiss scholar who first made Pascal and Huygens’s theory of games of chance into a theory of probability (Shafer 1996b). Bernoulli did not talk of Nature as a witness, but this idea allows us to complete and make fully coherent Bernoulli's concept of probability. Like every respectable scholar of his time, Bernoulli rejected the idea that events can be determined by Blind Chance. There is no room for chance to determine events, because all things have been foreseen and determined by God. We have probabilities only because, unlike God, we do not know what will happen. All probability is subjective. Yet Bernoulli's subjective probability is a far cry from the subjective probability of twentieth-century Bayesians. We do not learn it by introspection. Often we can learn it only approximately, by long observations of frequencies in the world, and in this sense it is decidedly objective.

In order to see the coherence in Bernoulli's thinking, we must imagine an ideal level of knowledge, a level intermediate between us and God. Bernoulli's probabilities are the subjective probabilities of a witness at this intermediate level. They are subjective inasmuch as they are relative to the knowledge of this witness. But they are objective inasmuch as the witness is ideal. These probabilities are validated by what actually happens in the world, allowing actual witnesses to approach the position of the ideal witness through their experience.

Why call the ideal witness Nature? I make this claim on the word "Nature" in order to make clear my agreement with Bernoulli's rejection of determination by chance and my disagreement with those who use Nature as a modern and approving synonym for Blind Chance. In the twentieth century, rejection of Blind Chance no longer goes without saying. The idea of determination by chance is very alive in our culture and accepted in much of our scientific literature. Everyone who reads applied probability and statistics understands that phrases such as "stochastic mechanism" and "random process" are meant to evoke determination by chance. Classical (i.e., nonBayesian) statisticians often speak of the random determination of steps in a stochastic process by Nature. Nature has become an actor, who rolls her dice and uses the outcome to decide what to do. This is pleasantly anthropomorphic, but in my view empirically empty. Once we have said that Nature cannot predict what will happen any more than if she were rolling dice, nothing is added by pretending that she does roll dice and then acts on the outcome. In order to stay in the realm of the empirically meaningful, we should content ourselves with the idea of Nature as witness and predictor, for in this role Nature is the idealized limit of actual or potential scientists, and we can cash out statements about what Nature can or cannot predict in terms of our own achievements and eventual ambitions with respect to prediction.

In contemporary scientific discourse, "nature" represents quite broadly the ground intermediate between the huma witness and bare reality. The laws of nature, which we may sometimes perceive at least through the glass darkly, are laws that reality follows, regardless of how we imagine reality to be determined. By claiming "Nature" as the name of my ideal scientist, I stake a claim on this intermediate ground, a claim to be upheld equally against incursions by those who would exaggerate the role of metaphysical suppositions about the determination of reality and those who would exaggerate the role of the actual solitary witness. I mean to reject both the classical statistician's Blind Chance and the Bayesian statistician's insistence on using probability only to describe opinions of actual witnesses. By analyzing causality in terms of "Nature's predictions," I acknowledge the objective nature of causality—its independence of the limitations of specific witnesses—while at the same time rejecting the notion that it depends on some untestable metaphysics of determination.

3 Towards an Intellectual History of Nature as Ideal Witness

I have presented the idea of Nature as ideal witness as my own elaboration of the thinking of Jacob Bernoulli. This is an appropriate acceptance of responsibility; I do not want to condition my adoption of the idea on the claim that particular historical figures would agree with me. But I must also acknowledge other predecessors. In fact, the idea of an ideal witness (if not the name "Nature" for her) has a long history. Many of Jacob Bernoulli's most thoughtful successors, including Antoine Augustin Cournot (1801-1877), Charles Sanders Peirce (1839-1914), and Frank Plumpton Ramsey (1903-1930), resorted to an ideal witness, conceived of as a limit of actual and potential witnesses, in order to explain objective probability.

Cournot, a prolific French mathematician, economist, and philosopher, deserves to head this list, for he developed the idea of an ideal witness in a whole series of treatises (Cournot 1843, 1851, 1861, 1875).[3] His name for what I call Nature was "l'intelligence supérieure."[4]

Cournot borrowed the idea of a superior intelligence directly from the French mathematician Laplace (born Pierre Simon, 1749-1827), who had used it to explain not

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[3] For a recent philosophical appreciation of Cournot's ideas, see Martin (1996).

[4] I am endebted to Bernard Bru for directing my attention to Cournot's, which I had not studied for over twenty years.

probability but determinism. As Laplace explained in 1776,[5] a sufficiently superior intelligence, one capable of apprehending all the details of the present state of the world, could predict the future fully and perfectly from the present using a small number of laws. Laplace chose to emphasize a fictional superior intelligence in his formulation of determinism in order to drive home the point that we humans are in a less exalted position. We must rely on probability and on the mathematical theory of probability, a theory in which, as it happens, Laplace was already the unsurpassed master.[6]

Although Laplace found it convenient to proclaim Nature deterministic and probability subjective (this served to place his work on astronomy at the pinnacle of science while at the same time glorifying his work on probability as the basis of human reasoning), he was a careless philosopher, and in practice his probabilities seemed objective at least as often as subjective. In order to remedy this incoherence in his great

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[5] This is the date when Laplace first declared his determinism in print. It later played a central role in his *Essai philosophique sur les probabilités*, in its many editions from 1814 to 1825 (Bru 1986, pp. 251, 289).

[6] Both the originality and influence of Laplace's determinism are often exaggerated. His conception of determinism was not at all original, and it was at odds with the view of many of the contributors to probability who preceded him in the eighteenth century or followed him in the nineteenth. Many of them shared with Jacob Bernoulli the more pious view that the future is up to God, who is not obliged to determine it in a manner explicable to a human-like intelligence, no matter how superior. Gottfried Wilhelm Leibniz (1646-1716), for example, believed that only finite things can be predicted, whereas infinite things remain contingent, being known to God by vision rather than by demonstration (Parmentier, 1995, p. 28). And the inventors of statistical physics, especially the British scientists James Clerk Maxwell (1831-1879) and William Thomson (1824-1907), had views closer to Leibniz than Laplace (Smith and Wise, 1989, pp. 430, 632).

Nor was Laplace's subjective probability popular with the determinists of the nineteenth century, even in France. The French determinists most influential in science, Auguste Comte (1789-1857) in physics and Claude Bernard (1813-1878) in medicine and biology, were sharply hostile towards probability.

mathematical predecessor, Cournot gave his own twist to the idea of a superior intelligence. According to Cournot such an intelligence would have capacities analogous to those of humans but far more powerful—she would be neither God nor man, but "would have a place only in the theological World of the good and bad angels" (Cournot 1875, p. 70).[7] And she would differ from us not by dispensing with probabilities but by getting them right (Cournot 1843, p. 60). Hers would be the objective probabilities.

Cournot accepted determinism at least in part; he agreed that many individual processes could be predicted in the fashion that Laplace imagined. But he believed that such processes interact in fortuitous ways, foreseen by God (the sovereign intelligence) but not by any intelligence, even superior and theoretical, whose capacity of reason is analogous to our own. Such fortuitous interactions (as when, to cite Cournot's favorite example, a roof tile, following its determinate course, hits the head of the philosopher, heading on his own independent determinate course towards a mailbox) give reality to the idea of chance or objective probability.

Cournot's idea of the intersection of independent causal lines was convincing to hardly any of his nineteenth-century readers. Among French philosophers, it was discussed only to be rejected.[8] It certainly found no place in the doctrines of his British contemporaries Leslie Ellis and John Venn, who based their own version of objective probability on a less subtle equation of probability with frequency. But his idea of a superior intelligence who has objective probabilities—or least his idea of objective

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[7] My translation.

probabilities as probabilities scientists would approach in the limit after indefinite investigation, finds echoes in the work of many later writers, including Charles Sanders Peirce in the nineteenth century and Frank Plumpton Ramsey in the twentieth.[9]

We find further echoes in recent work by analytic philosophers. D. H. Mellor, after discussing the idea of objective probability for many years, writes recently, "Maybe the All-Seeing should have no degrees of belief other than 1 and 0, but he can still know the world to be such that we should" (Mellor 1991, p. 253). Yet more recently, in Michael Woods's posthumous work on conditionals (1997, pp. 83-84), we find the conclusion that objective probability is subjective probability from "an ideal epistemic standpoint." Woods's ideal epistemic standpoint is my Nature.

In sum, the idea that objective probabilities are the probabilities of an ideal witness has a long history. Aside from my adoption of "Nature" as the name of the ideal witness, the main innovation in my work is to emphasize the evolution of her probabilities and to locate the meaning of causality in this evolution. Whether the course of the world is predetermined by God, left to Blind Chance, or simply chaotic are

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[8] It should be added that in recent decades Cournot has received much greater notice from French philosophers of science. His books were all republished by Hachette during the 1970s and 1980s.

[9] In 1928, Ramsey wrote, "Chances are degrees of belief within a certain system of beliefs and degrees of belief; not those of any actual person, but in a simplified system to which those of actual people, especially the speaker, approximate" (Ramsey 1990, pp. 104). Later, he adds, "We do, however, believe that the system is uniquely determined and that long enough investigation will lead us all to it. This is Peirce's notion of truth as what everyone will believe in the end; it does not apply to the truthful statement of matters of fact, but to the scientific system" (Ramsey 1990, p. 161). See also Sahlin 1990, p. 115.

metaphysical questions with no bearing on the truths of causality. Causality is an idea with empirical meaning, rooted the possibility of prediction and its limits.

4 The Inadequacy of Stochastic Processes

Causal understanding in terms of probability trees does not necessarily reduce to causal understanding in terms of stochastic processes. A stochastic process, interpreted causally, is equivalent to a special kind of probability tree for Nature–one in which the instantaneous events represented by situations are all labeled with precise physical times. In general, a situation in a probability tree for Nature cannot be labeled with a precise physical time unless it is refined, as in Figure 4.

One might think, at first blush, that causal regularities expressed in a probability tree can always be refined to more detailed regularities expressed in terms of events at specified times as in Figure 4. Such refinement is indeed always possible in a purely mathematical sense, but we have no guarantee that it will be valid in the Nature's experience. As we saw in Figure 3, Nature's ability to make probabilistic predictions may disappear when she refines her event tree. Experience teaches us that regularity can dissolve into irregularity when we insist on making our questions too precise, and this lesson applies in particular when the desired precision concerns the timing of cause and effect. It applies to the natural sciences (where the timing of events may depend delicately on initial conditions) as well as the social sciences. Since Nature represents a limit of capacities of actual scientists, this lesson applies to her as well.

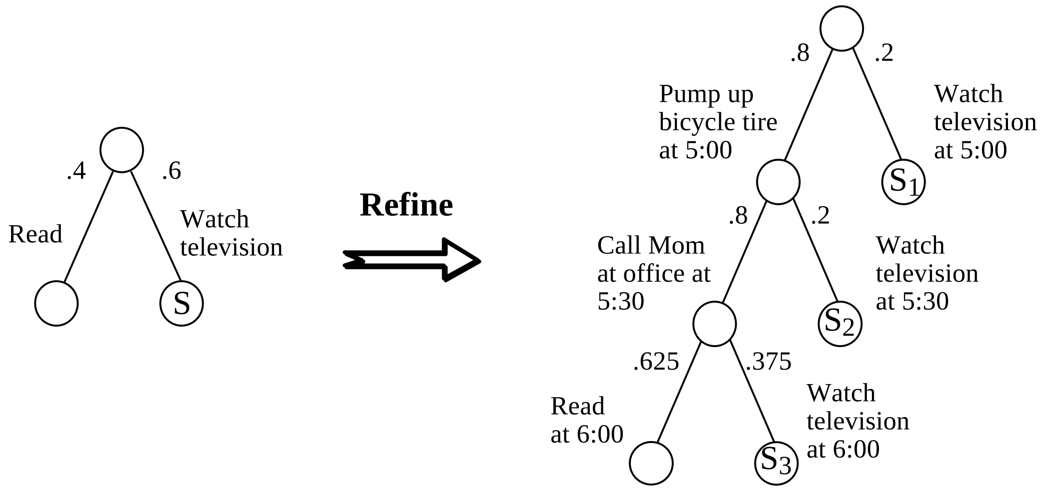

Figure 4 Here the more refined tree breaks the instantaneous event S into more specific events that have precise physical times. The more refined tree represents a discrete stochastic process, whose successive steps happen at fixed physical times no matter how events unfold. The less refined tree, on the other hand, cannot be interpreted in this way.

5 A Framework for Causal Debate

By recognizing that causal structures do not always extend to equally crisp deeper causal structures, we can keep causal debates within the bounds of common sense. Suppose the probability tree in Figure 5 is Nature's tree for a certain society. This means that no conceivable scientist, no matter how much she witnesses, can improve on its predictions of the sex, education, or income of a particular person in that society. At the point, for example, where a girl is conceived, no scientist observing the conception can do better than give 50-50 odds on whether she will get 8 years of schooling or 12. This is how the society works; as Nancy Cartwright (1996) puts it, the socio-economic machine operates so that we get this result. When people differ about the desirability of the results given by such a machine, they are likely to want more causal information. How is the machine made to work in this way, and what is the range of possibilities for how it might work differently? Though important, these questions do not necessarily have crisp answers, and meaningful debate is possible only when we acknowledge this.

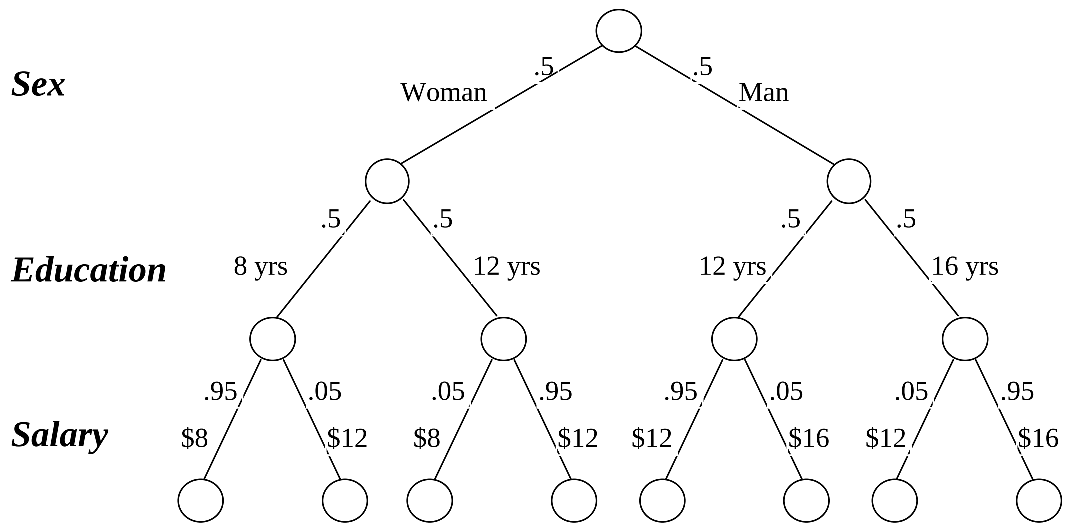

Figure 5 The norms of an imaginary discriminatory society. This society educates men more than women, but there is some overlap. People are usually paid in proportion to their education, but employers may deviate from proportionality for an exceptionally capable or hapless employee, provided they stay within the range of pay customary for the employee's sex.

Consider the determination of a woman's level of education. Perhaps Nature can say something about this. Perhaps when Nature witnesses certain events in a woman's childhood she changes her predictions about how much schooling the woman will receive. Figure 6 gives an example, in which we suppose that the experience of being a girl scout encourages further schooling. But it is not guaranteed that Nature will witness such regularities. Perhaps the proportion of girls becoming scouts and the schooling received by scouts and non-scouts varies so unpredictably that Nature cannot make probabilistic predictions, as indicated in Figure 7. Perhaps there are no signals that can help Nature predict in advance the amount of schooling a girl will get.

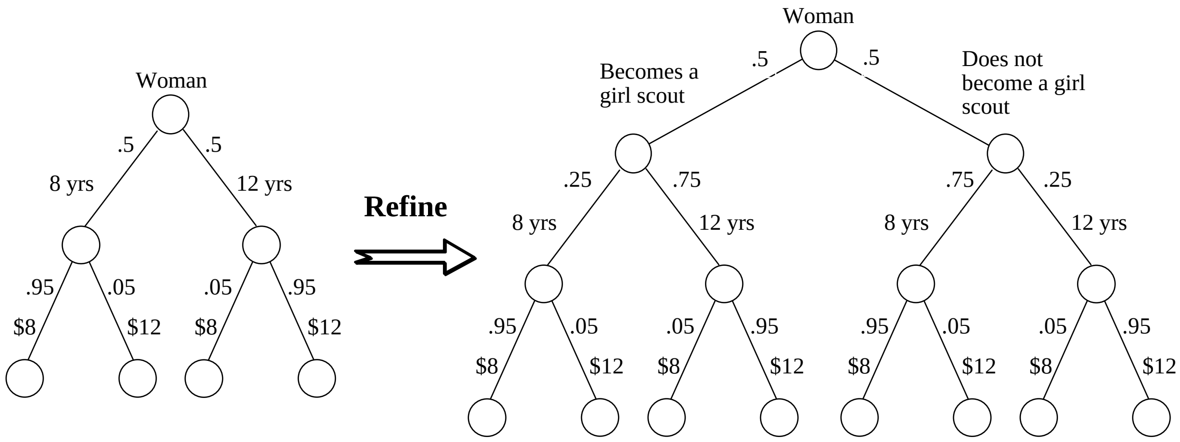

Figure 6 Some detail about how the educational level of a woman is determined. Notice that the refinement agrees with all the causal assertions in the original tree. When a woman leaves school after eight years, Nature gives her a 5% chance of earning $12. How she decided to leave school does not matter.

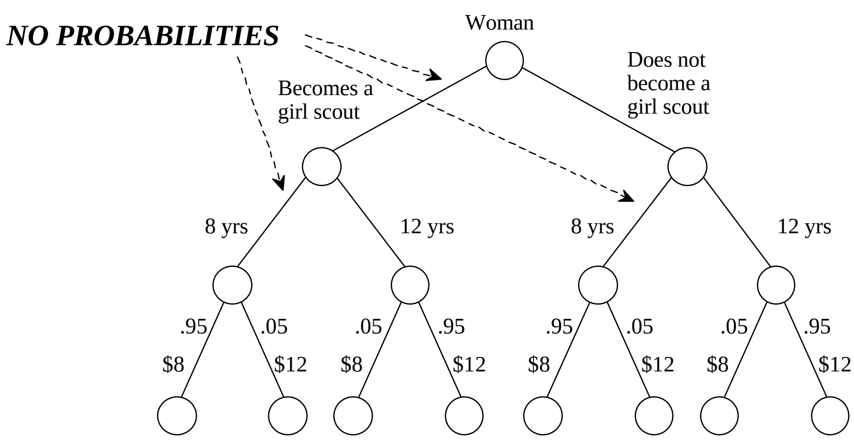

Figure 7 In this version of the story, which remains consistent with Figure 5, Nature does not witness any stable pattern in the proportion of girls who become girl scouts or in the proportion of girl scouts and non-girl scouts who finish 12 years of schooling.

If Figure 6 is a correct description of how the society operates, then the question of further refinement immediately arises. If steps are taken to get more young girls into the scouts, will more women complete 12 years of schooling? If, for example, the mothers in the Parent-Teacher Organization succeed in enrolling 90% of girls in the scouts, will the proportions of scouts and non-scouts finishing 12 years of schooling remain unchanged, so that the total proportion of women finishing 12 years increases from 50% to 70%, as in the tree on the left of Figure 8? And will most of these better-educated women get better paying jobs, as also indicated in that tree? Or will the society perhaps persist in limiting the proportion of women with 12 years of schooling to 50%, as in the tree on the right in Figure 8?

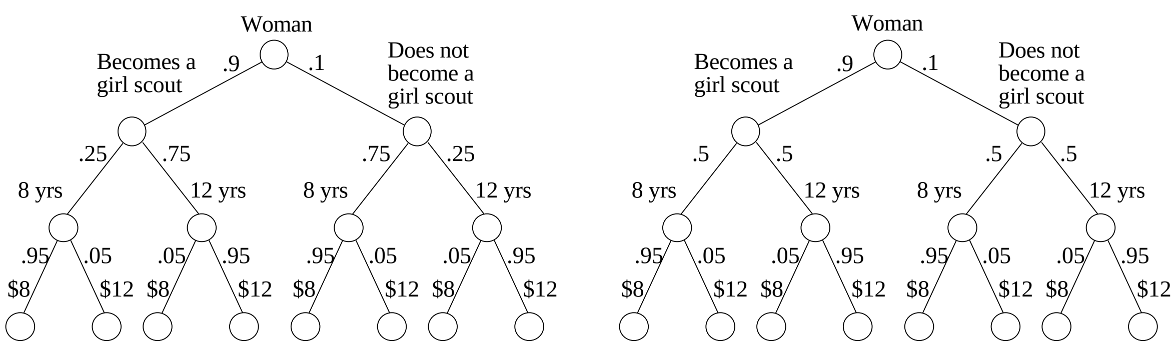

Figure 8 In the story on the left, the larger proportion of girl scouts leads to a larger proportion (.9x.75 + .1x.25 = .7) of women finishing 12 years of schooling. In the story on the right it does not.

Common sense says that these questions do not necessarily have determinate answers. Whether the new scouts clamor for more schooling, whether more schools are built and more teachers hired—this may depend on how well the new scouts are mentored, who control school finances, and countless other contingencies. Or it may simply be unpredictable. When Nature sees the circumstances, she may or may not be able to make some predictions.

It is sometimes helpful to think in terms of the breadth of a particular causal claim. We begin by supposing that Figure 6 applies to a particular society, situated in a certain time and place. Then we ask how much more widely some of its aspects apply. To what extent does the particular relation among sex, scouting, and education that Nature witnesses in this society apply to slightly different societies at slightly different times? We can expect only very nuanced answers to such questions. Causal relations in a particular society can often be extrapolated only to a limited extent.

Regularities witnessed by Nature, when known to individuals, can be used by those individuals as a guide to action. In a society where Figure 6 holds, a mother who wants her daughter to have more schooling will be wise to encourage the daughter to become a girl scout. But such guides to action become less reliable as we move outside the circumstances where we know Nature witnesses the regularity. When all the parents of girls change their behavior, the society itself has changed, and what causal regularities we or Nature will then witness is a new question (Lieberson 1985).

6 Determinism and Free Will Within Nature's Event Tree

As Laplace's formulation makes clear, determinism is a hypothesis about predictability. One can believe that all things were determined before the beginning of time, perhaps by God, without being a determinist in Laplace's sense. Determinism goes further; it says that a sufficiently perceptive and well-informed witness can predict the course of events. There are general laws, sufficiently simple that this ideal witness can use them, together with initial conditions, to predict the future fully and exactly. Thus determinism amounts to a special hypothesis about Nature's event tree, the hypothesis that Nature can predict every step in her tree with probability one. According to this hypothesis, the tree does not really branch; it is merely a long chain of inevitable steps.

Conversely, when we reject determinism and suppose that Nature's event tree does branch, we are not necessarily rejecting the hypothesis that God knows everything in advance. We are merely rejecting the hypothesis that any human-like intelligence could predict everything in advance.

It is generally agreed that determinism has been refuted by the success of quantum mechanics. This refutation may be inconclusive at the macroscopic level where most discussions of causality are located, but here, too, there is now widespread sentiment against determinism. The conception of causality advanced in this paper can only reinforce this sentiment, for the predictions we can make in the social, biological, and practical sciences are so far from categorical that it seems plausible and reasonable to hypothesize at most probabilistic knowledge for an ideal witness who represents the limit of what we might achieve.

By freeing us from any commitment to determinism, the idea of Nature's event tree allows us to understand causality in the most natural way. As S. N. Bernstein (1932) pointed out, causality is inherently in conflict with determinism, for causality requires possibility: there must be more than one way that an event can come out if how it comes out is to make a difference in how something else comes out.

The most debated aspect of determinism's suppression of causality is, of course, its suppression of free will. It is difficult to see how there can be freedom without possibility. In contrast, the conception of causality represented by a branching event tree for Nature poses no problem for free will. While remaining entirely agnostic about whether predestination by God or later determination by Blind Chance somehow renders the freedom of the individual illusory, we may suppose that Nature, at any rate, participates fully in the illusion. From Nature's point of view, an individual is free to perform an act precisely when Nature cannot predict whether he will perform it or not.

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