The Open Future and Its Exploitation by Rational Agents

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Abstract Branching along the time dimension provides a dynamic, four-dimensional, treelike space-time structure that explains many features of the physical world. The list includes temporal asymmetry and directionality, time flow and the existence of "now," physical versus logical possibility, the openness of the future, quantum probabilities, and superpositional collapse. This chapter discusses these and how agents use the open future in order to act intelligently and rationally.

Branching Along the Time Axis

A single four-dimensional manifold or "history" of the world (a "Minkowski world," or, to allow for general relativity, a curved space-time manifold) extends from the Big Bang to the end of time if there is one, or indefinitely, if there is not. A "slice" of a history is a three-dimensional instantaneous state of such a manifold. In branching space-time, histories branch along such instantaneous slices, that is, "spacelike hypersurfaces," and the branching is toward the future, not the past. (The fact that there is no branching toward the past reflects our conviction that the world has a *unique* past. It could not be true both that the man from Stratford was the author of *Hamlet* and also that Bacon was.) A fan of branches above the first branch surface connects with a single history extending below. The overall structure

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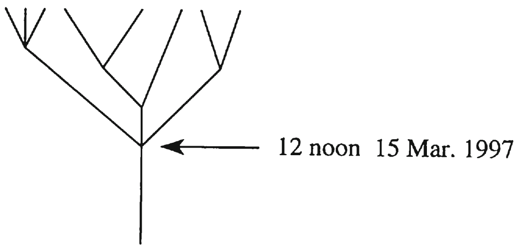
is that of a tree, with an unbranched trunk up to a certain point and a multitude of branches above that. Since the branches themselves branch upward, the branching is very dense.[1]

The Direction and Flow of Time

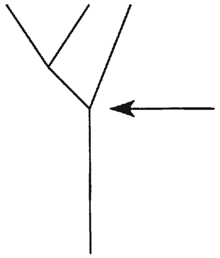
Because branching is only toward the future, temporal asymmetry and directionality are built into the structure of the universe. By definition, the "past" is constituted by the single trunk, the "future" by the branches, and the "present" by the lowest branch point or branching hypersurface on the tree. The "flow" of time consists of the progressive movement of the first or lowest branch point up the tree, brought about by "branch attrition".[2] Branch attrition consists in the following. Of all the branches which split off at the lowest branch point, one and only one is selected to become part of the trunk, and the others vanish.

The progressive disappearance or vanishing of all branches but one, at the lowest branch point of the tree, results in a new branch point becoming lowest and therefore "present." This is a fairly heavy-laden metaphysical idea. It is both ontological and dynamic and is not intended as a metaphorical or analogical description of the world, but as literal and precise. In the branch model presented here, the branches really do fall off in the way described, and their falling off constitutes the flow of time. Their progressive disappearance can also be compared to Aristotle's "transition from actuality to potentiality," which in modern physics consists of the collapse of the wave function brought about by interaction with a measuring device (Heisenberg 1958, pp. 53–58). Unlike the "mind-dependence" theory of temporal becoming (see Grünbaum 1963, Chapter 10), in which the passage of time is a subjective illusion, time flows in the dynamic branched universe whether conscious beings perceive it or not. This is illustrated by Figs. 1 and 2 below:



[1] McCall (1994) contains a detailed account of the branching space-time model discussed here. Belnap (1992) and Belnap et al. (2001) introduce a similar model, the details of which differ from McCall's. The two models bear only a superficial resemblance to the Everett-Wheeler many-worlds interpretation of quantum mechanics.

[2] For an account of how branch attrition in the model corresponds to the flow of time, see McCall (1976, 1984, 1994, 1997).



Physical Possibility and Openness

Indeterminism is built into the model. In the set of all branches that extend into the future at the first branch point, each has an equal chance of being selected as the "actual" branch that becomes part of the past. At the level of the present, branch selection is random. Branching in the model is discrete rather than continuous, there being a small finite, nonzero interval between successive branch points. A future event is *physically possible*, relative to the present state of the world, if it occurs on some future branch. More precisely, E at time t_2 is possible, relative to conditions prevailing at a branch point or branch surface X at time t_1, if E at t_2 is on some branch above X at t_1. For example, it is physically possible, in 2010, for a traveler in Montreal to be in Vancouver 5 h later, but it is not possible to be there 5 min later.[3] This holds even though it is *logically possible* to be there 5 min later or 5 nanoseconds later. The branched model yields a clear, unambiguous difference between logical and physical possibility. The same holds of physical necessity. What is physically necessary, relative to time *t*, is what is on all branches above *t*. It is physically necessary for water heated in an open container above 150 °C to boil, but it is not logically necessary. An open future is a future that contains mutually incompatible, physically possible events.

Probability, and Superpositional Collapse

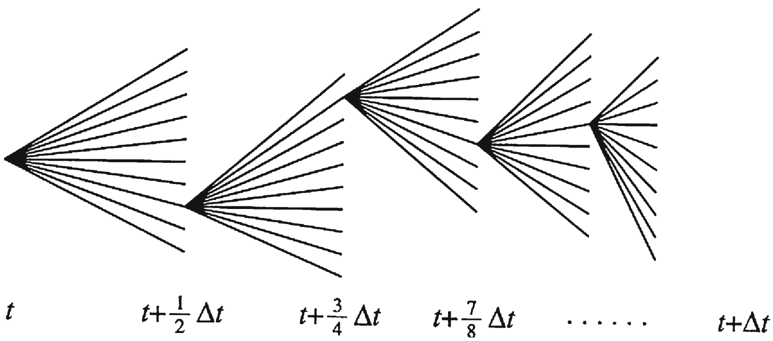
The *probability* of a future event is given by the *proportionality* of future branches on which the event occurs. For example, if there are 100 future branches above the first branch point of a tree at time t_1, and if an event of type E occurs at time t_2 on 67 of them, then p(E-at-t_2), relative to t_1, is 0.67. Of course p(E-at-t_3), relative to t_1, may take a different value. The notion of "proportionality" among sets of future branches is tricky and needs to be defined precisely.

[3] Concerning the concepts of physical possibility and physical necessity, see McCall (1969).

Some probabilities in the physical world take irrational values and require careful handling. For example, a vertically polarized photon about to enter a two-channel polarization analyzer oriented at an angle of 34° to the vertical has a probability of $\cos^2 34°$ of emerging in the "+" channel and a probability of $\sin^2 34°$ of emerging in the "–" channel. These are irrational numbers. $\cos^2 34° = 0.68729\ldots$, a non-repeating decimal, and $\sin^2 34° = 0.31270\ldots$. How can an irrational probability value be represented by a relative proportion of branches above a branch point?

The answer lies in considering a decenary tree, a space-time tree that splits into 10 branches at the first branch point, with every branch dividing in 10 at each successive branch level.[4] A decenary tree can be compressed into an arbitrarily short but nonzero temporal interval, say Δt, as follows. The tree branches in 10 at $t = 0$, and each branch divides in 10 at time $t + ½\,\Delta t$, at $t + ¾\,\Delta t$, at $t + \frac{7}{8}\Delta t$, …. etc. By $t + \Delta t$, the decenary tree will contain a non-denumerable infinity of branches. See Fig. 3 below:

How does it come about that exactly $\cos^2 34° = 0.68729\ldots$ of these are + branches, and $\sin^2 34° = 0.31270\ldots$ are – branches? Well, suppose that six of the first ten branches are + branches, three are – branches, and one branch is "open," meaning that it is neither + nor –. Once a branch is +, or –, it stays that way till the top of the decenary tree. At the second level, at $t + ½\Delta t$, the one open branch divides into eight + branches, one – branch, and one open branch. At $t + ¾\Delta t$, the open branch divides nto seven + branches, two – branches, and one open branch. At $t + \frac{7}{8}\Delta t$, the open branch splits into two + branches, seven – branches, and an open branch. And so forth. The decimals 0.68729… and 0.31270… are simply reproduced in the decenary tree. At the end, $t + \Delta t$, exactly $\cos^2 34°$ of the totality of branches in the tree will be branches in which the photon exits in the + channel, and $1 - \cos^2 34° = \sin^2 34°$ of the totality will be – branches. In addition, there will remain one open branch, which can become arbitrarily either + or – at the initial node of the next level of decenary trees. (When a non-denumerable set is divided into two proper subsets, the addition of one more unit to either of the subsets makes no difference to the overall relative proportionality.)



[4] Decenary trees are described in McCall (1994), pp. 88–92.

We may call a decenary tree a “prism” of temporal height Δt. The entire branched space-time universe is a *prism stack*, with a new prism standing at the upper (i.e., later) end of each complete path through the prism immediately below it. Despite what Georg Cantor says about there being no well-defined relative proportionalities in infinite sets, decenary trees provide exact probability values for future events, even when these values are irrational numbers. The reason why decenary trees are exceptions to Cantor’s generalization is because of the particular structure of the set of their branches. Suppose a vertically polarized photon enters an analyzer oriented at 34° to the vertical at time *t*. The probability of its emerging in the + channel, a result which corresponds to a + branch being the sole survivor of branch attrition in the appropriate prism stack, is precisely 0.68729…, and the probability of its emerging in the – channel is precisely 0.31270….

In quantum mechanics, the incoming photon, about to enter a measuring device (in this case a polarization analyzer), is said to be in a *superposition* of polarized states, written $|+\rangle + |-\rangle$. On measurement, the superposition *collapses* into one of these states. In dynamic branching space-time, the selection of one single branch out of a multitude of branches at a branch point provides an “objective” theory of superpositional collapse, that is, a theory of collapse that makes no reference to the existence of an observer.[5]

Branching Space-Time and Human Deliberation

As was said earlier, a branching future that contains physically possible, mutually incompatible events is “open.” When human beings deliberate over what to do (practical deliberation), or what to believe (cognitive deliberation), there are different options open to them. Let’s focus on practical deliberation. I have the choice of leaving early and walking home tonight or leaving later and taking the Metro. Each alternative is physically possible, and each has its advantages and disadvantages. In branching space-time, relative to “now,” there are walking branches and Metro branches, in relative proportions that yield $p(\text{walking}) = p_1$ and $p(\text{Metro}) = p_2$. Is it a truly random matter as to which “actual” branch is selected, among the huge number of future branches that confront me? If p_2 is considerably larger than p_1, the chances of my taking the Metro would seem to be a lot greater than walking. But is this all that can be said? Do I simply wait to see what set of future branches, the “walk” set or the “Metro” set, the actual branch falls into, much as I wait to see, in the polarization experiment, whether the actual branch turns out to be a “+” branch or a “–” branch? No. In day-to-day living, human beings are agents, not observers. The reason I eventually find myself on a Metro branch, rather than a walking branch, is not that random branch selection resulted in the actual branch falling into the larger of the two sets of future options. Instead, after due deliberation, I *chose* or *decided* not to walk. If the “walk” set had contained only a single branch, could I not have chosen it? Probably I wouldn’t, but *couldn’t* I have?

[5] See McCall (1995b, 2000a, b).

The process of deliberation, which Aristotle calls *bouleusis*, consists of three stages:

(i) Listing the alternatives that are open.
(ii) Evaluation, that is, assigning each alternative a weight, either positive or negative, and then weighing one alternative against another.
(iii) Choice of one alternative, resulting in a bodily movement that realizes it. Aristotle calls this *prohairesis*, deliberative choice.[6]

The history of philosophy has witnessed centuries of debate, beginning with the Stoics and St. Augustine, over whether in a world that is deterministic, or in which God knows what the future is going to be, humans can exercise free will. In the case of determinism/indeterminism, either (i) the action A that we perform is deterministically caused by our beliefs and our desires, which would make the performance of a different action B physically impossible, or (ii) the performance of A is a purely chance event. Both alternatives do violence to our deeply felt conviction that what we do is under our control, in some sense "up to us." Branching space-time, considered as a preferable replacement for rigid 100% determinism,[7] would not be much of an improvement if all it did was put human agents at the mercy of "probabilism" rather than determinism. Are human choices to depend on random branch selection, operating over different-sized sets of alternatives? This does not sound like a satisfactory basis for controlled human action, arising from deliberative reasoning. If the choices we make are under our control, they have to be to be grounded on something other than branch attrition.

Control

What exactly does it mean to say that, most of the time, we "control" our actions? A skilled golfer can play a "controlled slice," while a beginner can be plagued with uncontrolled slices. An emotional person may weep uncontrollably; a reserved person tightly controls any display of emotion. Interestingly, much human behavior falls into the category of being both controlled and indeterministic.[8] People walking in opposite directions down a crowded street, for example, rarely if ever bump into one another, but even a Laplacian demon could not predict the exact path that any individual chooses to follow. Brownian movement, exhibited by the random motions of molecules in a gas, differs in being indeterministic and *un*controlled. Small bumps and irregularities in the snow make a skier's precise trajectory indeterministic, but each turn is beautifully controlled. As every skier knows, there is a world of difference

[6] McCall (1987, 1999, 2008) and McCall and Lowe (2005).

[7] Branching space-time does in fact allow for particular instances of 100% determinism, in cases where all the branches above an A node are B branches. For example, in all instances where the two ends of a copper wire are connected to a battery, current flows in the wire.

[8] McCall (2009), pp. 146–48 and McCall (forthcoming).

between skiing in control and skiing out of control. Another indeterministic example, in this case highly rational and highly controlled, is playing chess. Chess-playing is an indeterministic process because the moves made by one's opponent are unpredictable. If they were predictable, chess would lose much of its allure.

Rational, Controlled, Indeterministic Processes

The vital step in understanding how deliberative action is rational, controlled, and indeterministic, as opposed to probabilistic, that is, based on random branch selection over sets of possible futures, lies in recognizing the mental element in action. If a human being consisted solely of a probabilistically functioning neural mechanism directing the movements of a material body, then indeed there would be nothing to deliberative choice above and beyond the random selection of an "actual" bodily movement from among different-sized sets of future alternatives. But in addition to brains, human beings have minds. The branching space-time model of the world, and the definition of what it is for the future to be "open", are conceived exclusively in the third-person mode, exemplified by how a scientist would describe an atom or a whale. But our direct experience of the world, and of ourselves, and how we interact with the world, is conceived in first-person terms, not third-person terms. In thinking, dreaming, desiring, intending, planning, and deciding what to do, we adopt a subjective stance, not an objective one. Human choices are essentially personal, subjective, and mental. This does not prevent their consequences from being far-reaching and objective. It is the subjective, mental element that makes deliberation rational and controlled, in addition to being indeterministic.

Without indeterminism, there would be no such thing as deliberation. As a matter of logic, one cannot deliberate and decide what to do if there is only one course of action open. As Richard Taylor remarks (1964), one can *seemingly* deliberate and decide to take a late train home, under the mistaken belief that the trains are still running. One can *seemingly* decide (and try) to move one's leg, unaware that the spinal anesthetic administered some hours earlier in the operating room has not yet worn off. In the train case, one can start the process by going to the station, that is, one can *initiate* the implementation of the decision to take a late train. But one can't *fully* implement it. In the leg case, one can't even initiate it. Unbeknownst to you, the alternative you chose was not open and did not exist. But these are pathological cases, in which two different alternatives seem to be open, but in reality only one is. The standard instances of practical deliberation logically require that there be at least two different alternative courses of action, and this implies indeterminism.

The mental element enters into practical deliberation at every stage. First, the deliberator must be *aware* of the existence of different possible options. Second, during evaluation, the assignment of appropriate positive and negative weights to the options is a judgemental activity of the mind, involving the use of practical reason. The process is a rational one, taking into account the strength of possibly conflicting impulses and desires, balancing short-term versus long-term considerations, and influenced by the probable impact of one's actions on others. ("Why did you even consider putting in a side order of clams when they always make you sick?" "Because I knew George was crazy about them and would lick the platter clean.") Third, the final choice at the end of the deliberative process can be a "difficult" one, meaning that its consequences may be grave, or that two different options are equally balanced. Buridan's ass starved to death, equidistant between two equally tempting piles of hay. A more intelligent being would flip a coin or simply make the kind of arbitrary choice we make at the supermarket in choosing one of a hundred identical cans of tomato soup. In all cases, the subjective role of the mind in decision-making is critical.

John Searle points out a characteristic feature of the subjective, first-person stance, one that sets it apart from third-person affirmations. This is, that in the realm of subjectivity, the distinction between appearance and reality no longer holds (see Searle 2004, p. 85). There is, for example, no difference between saying "I am in pain" and "It seems to me that I am in pain." In the case of practical deliberation, a strong subjective element characterizes both the evaluation of alternative courses of action and the eventual choice. Weighing options is not like weighing sugar. Options do not come with ready-made weights. Before one option can be weighed against another, it must be *weighted*, and the weighting process is a subjective one. One who *seems* to attach more weight to comfort than to convenience in traveling *really does* weight comfort over convenience. It is in the assignment of weights to options that deliberators exercise the first dimension of their control over the deliberative process. The second dimension emerges in the final choice.

Like the weighting of options, choice is a subjective phenomenon. In the world of the first-person, to *seem* to choose *is* to choose. To *seem* to be in pain *is* to be in pain. In order to appreciate the crucial role that subjective choice plays in decision-making, consider the difference between human decisions, in which the mind plays an essential role, and the decisions made by a probabilistically functioning neural mechanism. As was described above, probabilistic behavior in the objective third-person world is based on global random selection of an actual future from among sets of possible futures, these sets being of different relative proportions. If "persons" are merely neural mechanisms, then their "decisions" are modeled on this pattern. But in fact, a choice made by a human deliberator is very different. It is a mental event, not caused by or supervenient upon random branch selection in the physical world, but itself the cause of branch selection, and the accompanying bodily movement. A mental choice, with physical effects, is a paradigmatic example of mental causation. (On mental causation, see Kim 1998.) Significantly, this is not a case of causal overdetermination, since the physical event that the mental event causes, that is, the bodily movement, does not already possess a physical cause. This needs to be made clearer.

Indeterminism in the Brain

As was stressed above, without indeterminism, without at least two different possible optional actions stemming from the same set of initial conditions, there would be no such thing as practical deliberation. Suppose someone, X, is deliberating about whether to do A, B, or C. Throughout the entire deliberative process, these options remain "open," meaning that X can make a bodily movement initiating the implementation of any one of them at any time. In X's brain, there are motor neurons, the activation of any one of which will lead to implementation. Let n(A) be the neuron, the activation of which initiates the implementation of A, and similarly for n(B) and n(C). Before X reaches a decision, each motor neuron is potentially activat*able*, but it is undetermined which one will be actually activat*ed*. It is the indeterministic functioning of X's brain that keeps the options A, B, and C open. When X reaches a decision and chooses one of the three options, say option B, what causes the activation of motor neuron n(B)? We have already examined, and rejected, the hypothesis that n(B) is activated by random branch selection in the space-time model. There remains only one possibility, that the activation of n(B) is caused neither randomly nor physically, but by the mental, phenomenological event that we call "X's choice." Despite the misgivings of generations of philosophers since the time of Hobbes and Descartes, it would seem that mental causation plays an essential role in deliberation, decision, and action. One of the principal objections to invoking a mental cause in this context, namely, the easily made philosophical assumption that every physical effect must have a physical cause, is vitiated in this case by the fact that, because of the indeterministic functioning of the brain, the activation of the motor neuron n(B) has *no* physical cause. Instead it has a mental cause. Having no physical cause, the activation of n(B) is not causally overdetermined.

How Rational Agents Exploit Neural Indeterminism

Can the overall indeterministic functioning of the billions of neurons in the human brain be given a naturalistic explanation? Does such functioning have "survival value"? It seems logical to suppose that it does, and that the role of "keeping one's options open," played by neural indeterminism, was one of the most important factors in human evolution. Compare a human brain, that behaves indeterministically, with a deterministic neural mechanism functioning on a "stimulus/response" basis. When confronted with a challenge, whether for living space, or food, or physical combat, a creature with a one-option brain would seem to be at a disadvantage compared to a creature with a multi-option brain. An essential component of human rationality is *practical reason*, the ability to examine different courses of action and select the best. Without multiple options, generated by neural indeterminism, an agent is incapable of reasoning in a practical way. Of course, practical reasoning comes with a risk, namely, that one may choose the wrong option, a course of action unsuited to the prevailing situation. But human evolution demonstrates, I think, that living riskily brings higher rewards, and a higher level of development, than living safely and predictably.

A long time ago, Plato and Aristotle differed on the question of the Good, and its relationship to human action. Plato, the idealist, maintained that all of us, at all times, seek the good in the sense of acting in accordance with what we believe to be best. If we behave badly, it is through ignorance of where our true good lies.

Aristotle, the realist, believed that it was possible to know what is best, but not to do it. Of the two philosophers, Aristotle seems to be closest to recognizing not only the judgemental role of practical reason but also the possibility that ultimate choice may not accord with deliberative evaluation, with “what one thinks is best.” Aristotle judged that this was an evidence of human *akrasia* – “weakness of will.” This may or may not be so, but the possibility of “knowing the good and not doing it” seems an inevitable consequence of the power of deliberative free choice.

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