Philosophy of quantum mechanics

VU University Amsterdam: W_MASP_TF013 Lecture 7: 24/2/2015
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Today's lecture

- Recap
  - The Everett interpretation
  - The probability problem
- Papineau's defence of many worlds
  - No worse off than the standard view.
- Wallace's two responses to branch counting.
  - Branch counting is inconsistent over time.
  - There is no such thing as 'the number of branches'.
- The concept of probability
  - Set-up for decision theory.
  - Probability, frequency, and credence.
- The decision-theoretic strategy
  - Greaves' discussion of the Deutsch-Wallace proof of the Born rule.
  - Wallace's response to alternative rules.

Recap

The problem of outcomes

- The following three claims are mutually inconsistent.
  - A. The wave-function of a system is complete i.e. the wave-function specifies (directly or indirectly) all of the physical properties of a system.
  - B. The wave-function always evolves in accord with a linear dynamical equation (e.g. the Schrödinger equation).
  - **C. Measurements always (or at least usually) have determinate outcomes, i.e., at the end of the measurement the device indicates a definite physical state.**
    - **The Everett interpretation denies proposition C!**

The Everett interpretation

- The Everett interpretation:
  - The physical universe is *completely* described by the wave-function and the wave function *only* ever evolves linearly (e.g. via the Schrödinger equation).

- But doesn't introspection show that we don't enter into superpositions of distinct observations?
  - When observations 'superpose' they in fact *branch* or *bifurcate*.

A branching multiverse

- Interpreted correctly, the linear dynamics guarantees that observers have definite post-measurement observations...

$$\frac{1}{\sqrt{2}}|"hard">_o |"hard">_m |hard>_e + \frac{1}{\sqrt{2}}|"soft">_o |"soft">_m |soft>_e$$

- ...observer O has literally split into *two* observers.
  - One observes a hard result the other observes a soft result.

What it's like to be in a superposition

- Papineau (p240):
  - "From the subjective point of view, this wont feel like being a single person who somehow experiences both results. Rather it will feel, so to speak, like being two separate people, each of whom experiences a single result." A brain which gets into a superposition of registering 'up' and registering 'down' will come to underpin two separate centres of consciousness. These will share common memories, but will cease to gain any information about each other once the split has occurred."
- Why should it feel like that to have a superposed brain?
  - Short answer: Why should anything physical feel like anything?
  - Long answer: Natural selection has given rise to systems of psychological organization in which memories are restricted to 'decoherent' histories.

What about the basis problem?

- Basis problem:
  - If worlds are defined by superposition components in the fundamental state vector then they are basis-dependent.
- The "Oxford" solution:
  - Decoherence plus emergence.
- Hilary Greaves:
  - "Given the sorts of [physical states] in the actual world, we expect one (approximately defined) basis to be "preferred" in the sense that only when the universal state is expanded in that basis will it be possible for stable higher-level structures (tables, humans) to emerge within individual elements of the superposition."
    - In "Probability in the Everett Interpretation".

The probability problem

- Let the pre-measurement state be:

$$|"ready" >_m \left(\frac{1}{\sqrt{2}}|hard >_e + \frac{1}{\sqrt{2}}|soft >_e\right)$$

- The linearity of the dynamics entails that the microscopic superposition splits the measuring device, giving *both possible* outcomes:

$$\frac{1}{\sqrt{2}}|"hard" >_m |hard >_e + \frac{1}{\sqrt{2}}|"soft" >_m |soft >_e$$

- But if we know both outcomes will occur, then surely they occur with probability 1 rather than 0.5?

The probability problem (again)

- Furthermore, how do Everettians distinguish states like this:

$$\frac{1}{\sqrt{2}}|"hard" >_m |hard >_e + \frac{1}{\sqrt{2}}|"soft" >_m |soft >_e$$

- From states like this:

$$\frac{\sqrt{3}}{2}|"hard" >_m |hard >_e + \frac{1}{2}|"soft" >_m |soft >_e$$

- Don't both give rise to the same branching structure? What is the physical significance of their distinct branch weights?

Two probability problems

- Greaves (p110):

- The incoherence problem
  - How can it make sense to talk of probabilities (other than 0 or 1) at all, since all "possible" outcomes actually occur?

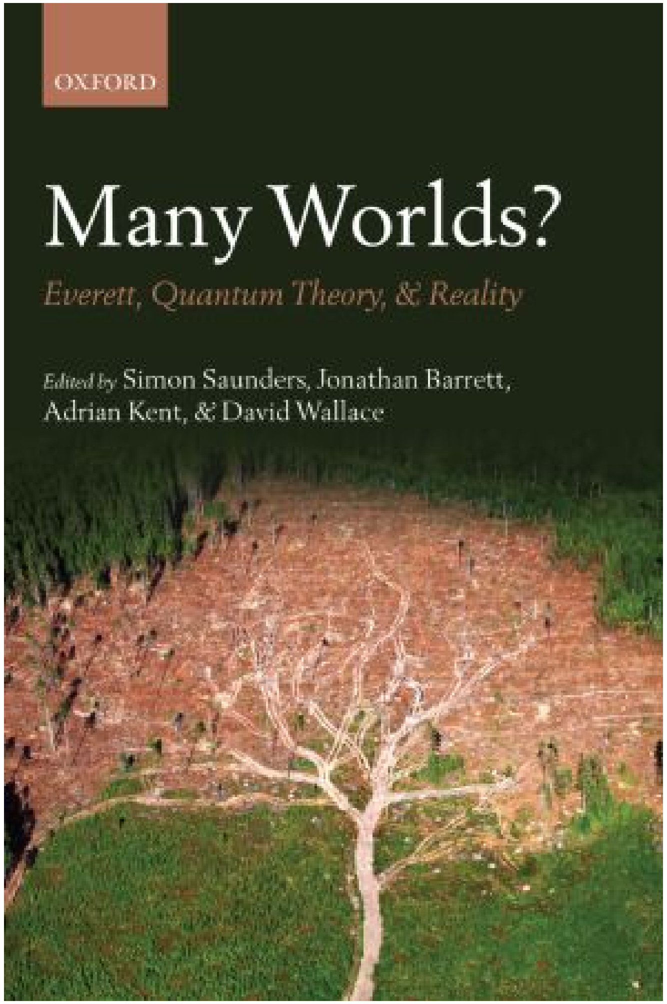
- The quantitative problem
  - Insofar as it does make sense to talk of nontrivial probabilities for branches, how can the probabilities in a many-worlds interpretation agree with those of textbook quantum mechanics (i.e. Born rule probabilities)?

The basic idea of the response

- A major source of objection comes from *conceptual confusion*:
  - Critics wrongly analyse probability in terms of frequency.
- Probability is best analysed in terms of the so-called principal-principle
  - Relating probability to rational action.
- This means that Everettians can
  - ...argue that orthodox views have just as much trouble explaining probability, so the criticism employs a double standard.
  - ...use principles of rationality to defend the idea that Everettian branch weights are probabilities, thereby explaining probability.

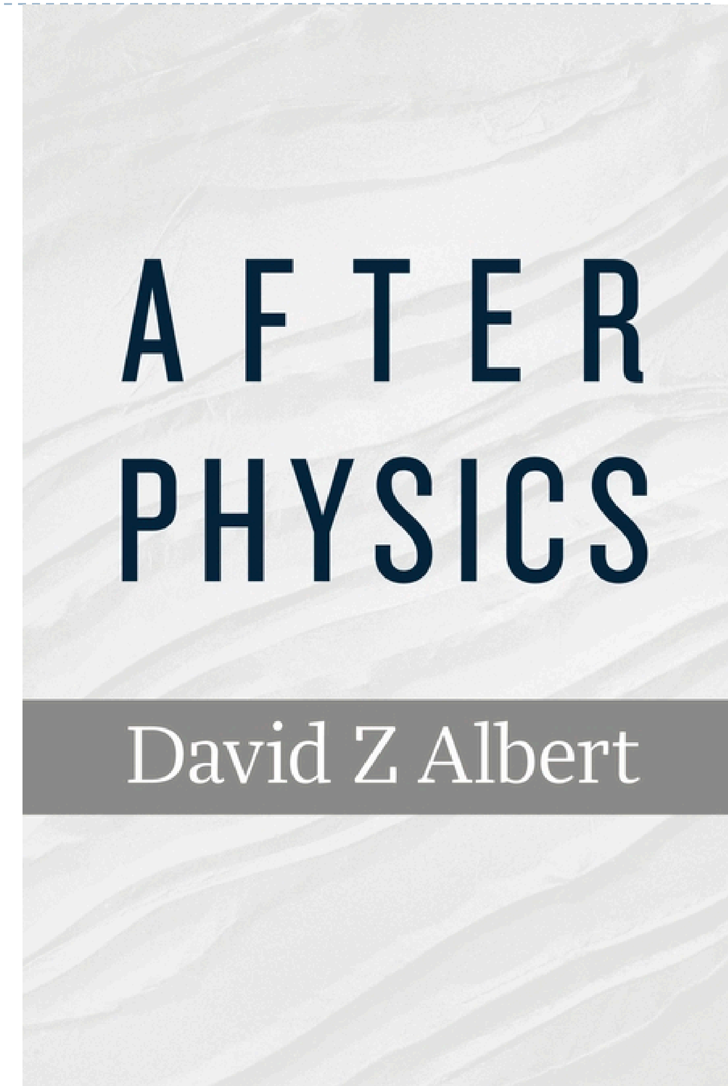
Navigating "Many Worlds?" (2010)

- Probability spans chapters 6 to 12.
  - 6 to 9 are defences of Everett, 10 to 12 are critiques.
- That's a lot!
  - What to focus on?
  - 7: Papineau (simple defence)
  - 8: Wallace (complex defence)
  - 11: Albert (objections)
- Actually, we will look at improved versions of these three papers!
  - You can also find online presentations:
    - http://www.perimeterinstitute.ca/video-library/collection/many-worlds-50-2007
    - http://users.ox.ac.uk/~everett/video.htm



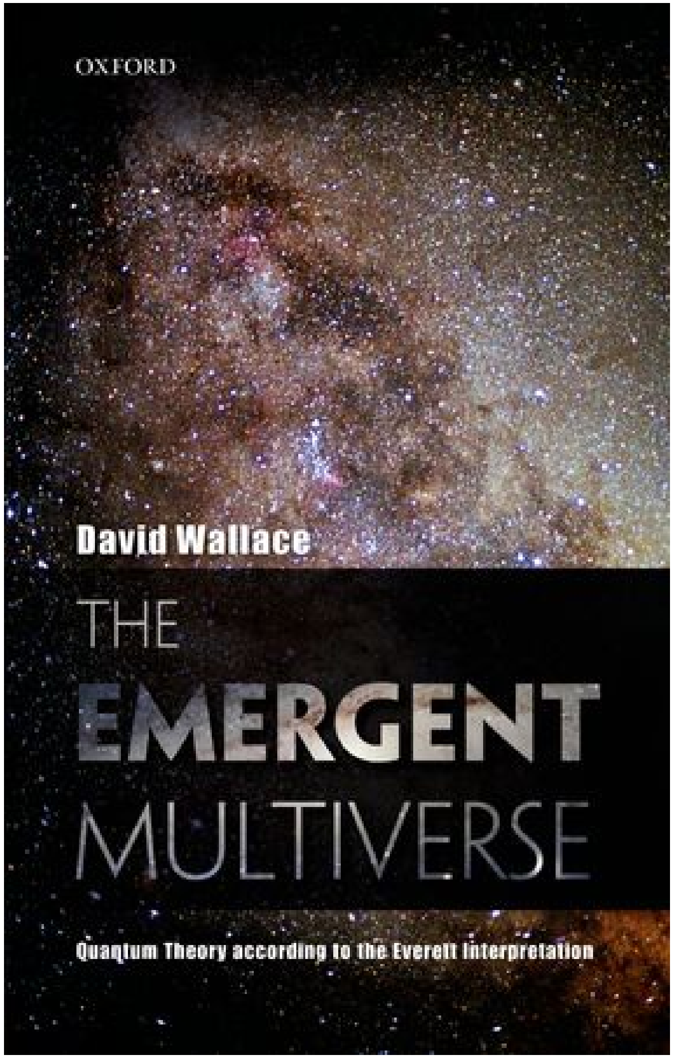
Navigating "After Physics" (2015)

- Chapter 8:
  - Probability problem is fatal
    - Thursday's reading
- Chapter 7:
  - Dynamical collapse theories
    - Defence of spontaneous collapse theories.
  - Next week's topic!



Navigating "Emergent Multiverse" (2012)

- Chapter 4
  - The probability puzzle
- Chapter 5
  - Symmetry, rationality, and the Born rule.
- Both will be posted to blackboard



Papineau's defence of Everett

Papineau's def. of probability problem

- "[The Everett interpretation] undermines itself by destroying any notion of objective probability. Quantum mechanics is, if anything, a theory which specifies the objective probabilities of certain results. But in what sense is there an objective probability for 'up' and 'down' in a spin measurement, if *both* results *always* happen?" (p239).

- Papineau aims to show:
  - "[The Everett interpretation] does leave objective probability as a mysterious notion. But it is no more mysterious than on the conventional view of the world."

Single results and probabilities

- Objection:
  - The probability of a given result means the probability *of that result happening*.
  - On Everett, both results (up and down) always happen.
  - So no sense can be made of the claim that 'up' has probability 0.6 (for example).
- Papineau's response:
  - This is a problem for the standard view too!
  - On the standard view, we don't get both results (up and down), we get *one* result (e.g. 'up').
  - But the fact that we got 'up' doesn't explain why the probability for 'up' is 0.6.
    - On both views this probabilistic fact is *additional* to the non-probabilistic facts about which results actually occur.
- Is this a good response?

Sequences of results

- Objection:
  - Granted: the fact that we got 'up' doesn't explain why the probability for 'up' is 0.6.
  - But: facts about what we got in a sequence of N experiments where N is large will explain why the probability for 'up' is 0.6.
- Papineau's response:
  - Same point applies!
    - Finite sequence of experiments *is* a single composite experiment.
      - The fact that we got up/up/up/down/up [etc.] does not explain why the probability for 'up' is 0.6.
  - We cannot identify the probability p with the frequency in the single actual sequence – since it may differ from p.
  - So on neither view do actual sequences fix probabilities.
- Is this a good response?

Statistical inferences

- Objection:
  - Granted, the inference from actual sequences to probabilities is mysterious on all theories.
  - But on the Everett theory we cannot find out about probabilities from actual sequences *at all*.
    - If all possible frequencies occur then how could we ever infer *the true* probability from them?
- Papineau's response:
  - Statistical inference is identical on either theory.
    - Note the frequency on your branch,
    - Infer that the probability is "close" to the frequency,
    - Hope you're not the unlucky victim of an improbable sample.
- Is this a good response?

The objection from improbable branches

- Objection:
  - There are branches where the observed statistics are misleading as to the true (QM) probabilities.
    - Consider colour measurements on hard electrons.
    - Seems that Everettians can only insist that we are on the "probable" branch with "typical" statistics.
- Papineau's response:
  - Objection to everyone so no objection at all.
    - There are *possibilities* where the observed statistics are misleading as to the true (QM) probabilities.
    - Orthodoxy can only insist that the actual world is a "probable" possibility with "typical" statistics.
- Is this a good response?

Infinite sequences

- Objection:
  - The true probabilities are identical to frequencies in (hypothetical) infinite sequences.
  - Only on the standard view can there be *a single* infinite sequence of outcomes to fix the probability.
- Papineau's response:
  - Is the identity claim intended as *a definition* of probability?
    - If it *isn't*, then one *cannot* identify the actual probability p from an infinite sequence (the relative frequency of 'ups' might be different from p).
    - If it *is*, Everett is in trouble. But it *shouldn't* be our definition…
      - The probability of finitely repeated trials cannot be explained by infinite (hypothetical sequences) unless those sequences have a certain *ordering*. Such non-existent results don't have any determinate order.
- Is this a good response?

Probability and action

- Objection:
  - Probabilities matter because they inform our best choice of actions.
    - In any chancy situation, agents ought to consider the probabilities of their alternative actions producing desired results.
  - But if you are sure both to win and to lose whenever you bet on some chancy outcome, then what does the probability of winning matter?
- Papineau's response:
  - The same problem can be raised on the standard view.
    - From their choices agents want their desired results *to happen*, they don't want their desired results to merely *be probable*.
      - A choice that makes a result probable, but does not make it occur, does not give you what you want.
  - Both views can take the *principal principle* as *a basic truth* that rational agents ought to choose those actions that maximize the known probability of desired results.
- Is this a good response?

Papineau's defence summarised

- The (mod squared) branch weights are probabilities because they *behave like probabilities* even for an Everettian with complete knowledge of the future.
  - They *respond to evidence* and *guide decisions* just as in orthodox theory.
  - The orthodox "ignorance about the future" requirement is metaphysical baggage that should be stripped from the concept of probability.
    - Similarly with the identification of probabilities with frequencies.

- But WHY do branch weights respond to evidence and guide decisions?
  - Everettians may not be able to *completely* explain why.
  - But they are at least as well placed to answer these questions as orthodoxy.

Is the orthodox view *worse off*?

- A puzzle to think about:
  - Orthodoxy thinks of the aim of rational action differently from Everettians.
    - Orthodoxy: an action is successful if it maximises expected utility (produces good results) in the presumed one actual future.
    - Everettians: an action is successful if it maximises expected utility over all future worlds weighted by their squared amplitudes.
  - A question for orthodoxy:
    - Why is maximising objective expected utility a good means to success in the one actual future?
  - This is not a question for Everettians.
    - Maximisation of objective expected utility is not some means to a further end (success in one actual future) but is the essential characteristic of a fully successful choice.

Wallace’s two responses to branch counting

The branch counting objection

- As defined by Wallace (2012: p119):
  - The problem is not that probability does not make sense.
  - It is that the numbers come out wrong.
  - There is an obvious probability rule to use:
    - ***Branch counting rule:*** *all the branches are equally real, so just give all equal probability.*
  - An experiment with N outcomes should have probability 1/N regardless of the weights of branches.
  - This rule is widely at variance with empirical data.
  - So many worlds is inconsistent with the data.

Response 1: diachronically inconsistent

- Consider the following set-up:
  - t_0: One branch at time (t0).
  - t_1: The branch splits into branches A and B.
    - Observer on A gets \$, observer on B does not.
  - t_2: Branch A splits into branches A1 and A2.
    - Observer on A with \$ splits. B remains unsplit.
- Now ask: at t_0, what probability should the observer assign to getting \$?
  - Branch counting rule:
    - The probability is ½ at t_1.
    - The probability is 2/3 at t_2.
  - Standard rule of probability calculus:
    - $\Pr(\$@t_2 \setminus \$@t_1) \times \Pr(\$\&t_1) + \Pr(\$@t_2 \setminus {\sim}\$@t_1) \times \Pr({\sim}\$@t_1) = ½$.

Branching indifference as ideally rational?

- According to Wallace: this motivates another axiom of rationality:
  - **Branching indifference**: An agent doesn't care about branching per se: if a certain operation leaves her future selves in N different macrostates but doesn't change any of their rewards, he is indifferent as to whether or not the operation is performed.
    - An operation might be splitting A into A1 and A2.
    - Since rewards ($) are not changed, the agent is indifferent to the branching of A into A1 and A2.
    - So it's rational for the agent to be indifferent to it, and keep the probability assignment to ½.
  - This "rationality axiom" plays a significant role in the Deutsch-Wallace proof – so I will return to it.

Response 2: no number of branches

- **Wallace** (2012: 120-1): "Very small changes in how the decoherence basis is defined, or the fineness of grain that is chosen for that basis, will lead to wild swings in the branch count. […] And if there is no such thing as branch count then there can be no branch count rule."
- **Greaves** (2007: 121): Decomposing the quantum description of the quantum state into branches allows for some vagueness as to what is the 'right' set of worlds:
  - The space of worlds can be "coarse grained" but there's no fact of the matter as to which "coarse graining" is correct.
    - But different coarse-grainings yield different branch counts.
  - The decoherence basis can be rotated slightly without loosing (approximate) decoherence.
    - But such slight rotations can yield different branch counts.

Branch counting in the orthodox view

- In the spirit of Papineau's defence Greaves writes:
  - "Even if the naïve counting measure were coherent, though, the objection would remain a curious one: it presupposes a dubious application of the principle of indifference (and might just as well be levelled against a single-universe collapse interpretation, in which all outcomes are "equally possible".

- Is there any reason, specific to collapse theories, for why collapse theories are not committed to branch counting?

The concept of probability

The importance of analysing concepts

- When deciding whether a theory explains X or eliminates X, we need to be clear about what we mean by 'X'.

- According to functionalism (a theory of explanation):
  - 'X' is defined by what X's do, or the primary "functional role" they play in the world.
  - A theory explains X iff it postulates underlying entities that "play the X-role".
- According to cautious functionalism (cf. Saunders ch.6)
  - A theory explains X iff it postulates entities that play *enough* of the roles that X was supposed to play.
  - We need to be aware that some things we attribute to the concept of X may be based on faulty theorising.

Example: solidity

- What's important to our concept of solidity?
  - 1. Being everywhere dense?
  - 2. Being disposed to resist deformation?

- Classical physics taught us that nothing satisfies 1.
  - Macroscopic objects are mostly empty space.
  - So does classical physics fail to explain solidity? Should we say that *nothing* is solid?
- Classical physics explains enough of our concept.
  - 2 is explained in terms of intermolecular forces.
  - Classical physics explains enough of the functional roles and therefore *explains solidity*.

Probability and frequency

- How should we functionally analyse ‘probability’?

- Here is a definition from a well-known engineering textbook:
  - “The probability of an event (or outcome) is the proportion of times the event would occur in a long run of repeated experiments.”
    - Johnson, R. A. (1994). Miller & Freund’s probability & statistics for engineers (5th ed.). p57.
- For example:
  - The probability of a “white outcome” given colour measurement of hard electron is equal to the proportion of times a white outcome occurs in a long run of repeated colour measurements.
    - Which for Everett is 1!
    - Game over already?

Finite frequentism

- Finite frequentism
  - Probability is to be analysed in terms of the outcomes of some finite long run of repeated experiments.
    - E.g. Probability that the coin lands Heads is the relative frequency of Heads in a long run of tosses of the coin.

- Somewhat implausible…
  - How long is "long" and what if the world is not generous enough to provide a long run of relevant sequences of events?

- For further criticism see:
  - Alan Hajek's "Fifteen Arguments Against Finite Frequentism" (*Erkenntnis* 1997).

Hypothetical frequentism

- Hypothetical frequentism:
  - Probability is to be analysed in terms of the outcomes of some hypothetical long (say, infinite) run of repeated experiments.
- Problems:
  - To give a definite answer as to how a chancy device would behave is to misunderstand chance.
    - Compare the finite with the infinite case, why is asserting what will certainly happen in the infinite case less fallacious than in a single chancy case?
- For further criticism see:
  - Alan Hajek's "Fifteen Arguments Against Hypothetical Frequentism" (*Erkenntnis* 2009).
    - "Probability is not recognizably a frequentist notion, however we squint at it" (p213).

Then what is the real connection?

- There *is* a connection between probability and frequency but it is *circular*:
  - Probability is what long term relative frequency tends to...*probably*.

- But then, do we actually understand probability?
  - Everettians: the core of our concept of probability is not frequency, but *decision-theoretic*.
  - Probability is best analysed via the "principal principle".

The principal principle

- (Objective) probability is that objective physical quantity that constrains rational *credence*.

- Credence = degree of belief
  - Understood as dispositions to behaviour, e.g., the odds at which you'd think it fair to bet on some proposition.
    - Note: not (necessarily) degree of belief that something will happen.

- Note: "credence" often called "subjective probability" while "chance" is used for "objective probability".

The "real" connection (again)

- Recall:
  - Probability is what long term relative frequency tends to…*probably*.

- The Oxford Everettians believe that their (non-circular?) analysis should be substituted in for "probably":
  - Probability is what long term relative frequency tends to …*in such a way that it would be irrational to not bet in accordance with the long term relative frequencies.*

The upshot of this analysis

- The Everettian is no worse off?
  - The Everettian need only show that there *can be* rational decision making in accordance with some objective quantity.
    - Papineau thinks this is sufficient and can be demonstrated in 6 pages!

- The Everettian is better off?
  - Can it be proved that the **only** objective quantity that constrains rational credence is represented by the Born rule measure (in an Everettian world)?
    - 'Probability of getting black is 0.9' means 'it would be irrational to (for e.g.) bet on white for odds less than 9 to 1'.
    - Deutsch-Wallace proof of the Born rule.

The decision-theoretic strategy

Goal of the Deutsch/Wallace proof

- If Papineau is right, then Everettians fair equally well as regards explaining probability.

- The Deutsch/Wallace proof serves to tip the scales, allowing the Everettians to explain probability.
  - Or at least, the aspect of the concept relating to the principal principle.

- It's a decision theoretic proof that a rational agent who believes she lives in an Everettian multiverse will nevertheless "make decisions as if" the Born rule gives the probabilities of outcomes.

Basic idea

- Axioms of rationality dictate that a knowledgeable Everettian rationally ought to set their credence's using the Born rule.
- This can be illustrated with *quantum games*.
- Using quantum games we can formulate rationality axioms that entail the Born rule given Everettian assumptions.
- Standard strategy for studying rationality in *decision theory*.

Decision theory

- A theory designed for the analysis of rational decision making under conditions of uncertainty.

- Key idea: Acts
  - An Act is a function from a set of possible states to a set of consequences.
    - Possible states: {raining, not raining}
    - Consequences: {get wet, don't get wet}
  - So the act of bringing an umbrella is the function that (e.g.) takes us from the state "raining" to the consequence "don't get wet".
- Decision theory places rationality constraints on Acts.

Decision-theoretic constraints on Acts

- Two examples:

- Transitivity
  - If an agent prefers A to B & B to C then she prefers A to C.

- Dominance
  - If A and B give the same consequence on some subset of states and A results in better consequences on the remaining subset then the rational agent prefers A to B.
    - "better" according to the agent's preferences.

Representation theorem

- There is a unique probability measure p on the set of states, and a utility function U on the set of consequences such that for any acts A and B, the agent prefers A to B iff the expected utility of A is greater than that of B.
  - Proved with decision-theoretic axioms.

- Expected utility of an act A:

$$EU(A) = \sum_{s \in S} p(s).U(A(s))$$

- Guarantees a role for subjective probability: any agent will act as if she is maximising expected utility with respect to some probability measure p.

Everettian application

- States
  - Set of future branches
    - Rather than set of possible states of the world.
    - E.g. Colour measurement of hard electron, states are {W, B}.
- Consequences
  - Things that happen to individual future copies of the agent on particular branches.
    - Rather than what happens to the agent per se.
- Acts
  - Function from states to consequences
    - An assignment of rewards to branches.

Quantum games / bets

- A chance set-up.
  - e.g. colour measurement on hard electron.
- A quantum act, or "payoff function".
  - Function from possible branches…
    - {White, Black}
  - …to consequences
    - E.g. $ reward or no $ reward.

- Together they make a quantum game
  - Useful for expressing the rationality axioms used to prove the desired result…

Everettian representation theorem

- By imposing rationality constraints on preferences among quantum games one proves an analogous representation theorem:
- Everettian representation theorem:
  - For any two Everettian Acts A, B, the rational agent prefers A to B iff EU(A) > EU(B).
    - Solves incoherence problem.
  - The probability measure p is the mod-square measure.
    - Solves the quantitative problem.
- Wallace claims to have proved this theorem!

The Deutsch-Wallace proof

- The *formal* proof involves a number of axioms and is quite involved.
- But we can provide an informal proof based on the three most philosophically significant axioms…
  - State supervenience
    - An agent's preferences between acts depend on what physical state they actually leave her branch in.
  - Equivalence
    - A rational agent is indifferent between any two quantum bets that agree, for each possible reward, on the mod-square measure of branches on which that reward is given.
  - Branching indifference
    - An agent doesn't care about branching per se: if a certain operation leaves her future selves in N different macrostates but doesn't change any of their rewards, she is indifferent as to whether or not the operation is performed.

State supervenience axiom

- State supervenience:
  - An agent's preferences between acts depend on what physical state they actually leave her branch in.
- Why believe it?
  - The agent's preferences supervene on the actual state of the branch.
  - What else could they supervene on?

Equivalence

- Equivalence:
  - A rational agent is indifferent between any two quantum bets that agree, for each possible reward, on the mod-square measure of branches on which that reward is given.
- Equal superpositions:
  - A: $\sqrt{1/2}\,|\uparrow>\,|\$>+\sqrt{1/2}\,|\downarrow>\,|\sim\$>$
  - B: $\sqrt{1/2}\,|\downarrow>\,|\$>+\sqrt{1/2}\,|\uparrow>\,|\sim\$>$
    - Equivalence states that rational agents will be indifferent between these two quantum games.
- Why believe it?
  - The only difference between A and B is inessential labelling.
    - The rational agent is indifferent as to whether we erase the labels.
  - So by state supervenience the agent must be *indifferent* between A and B.
  - The agent then ***acts as if*** spin-↑ and spin-↓ are ***equally probable***.
  - So the rational agent *sets her credences* in accordance with the Born rule!

Branching indifference (BI) axiom

- Branching indifference:
  - An agent doesn't care about branching per se: if a certain operation leaves her future selves in N different macrostates but doesn't change any of their rewards, she is indifferent as to whether or not the operation is performed.
    - We saw this earlier: it followed from applying the standard probability calculus to our simple branching situation (where A splits into A1 & A2).
- Why believe it?
  - The pragmatic defense:
    - "A preference which is not indifferent to branching *per se* would in practice be impossible to act on: branching is uncontrollable and ever-present" (2012: 170).
  - The non-existence defense:
    - A preference which is not indifferent to branching per se is meaningless: it would require there to be a determinate branch count.

Unequal superpositions and BI

- Unequal and equal superpositions:
  - C: $\sqrt{2/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\downarrow>|{\sim}\$>$
  - D: $\sqrt{1/3}\,|X>|\$>+\sqrt{1/3}\,|Y>|\$>+\sqrt{1/3}\,|Z>|{\sim}\$>$
- ***Which game would you prefer to play in a branching multiverse?***
- Note that a spin measurement in the $|\uparrow>|\$>$ branch of C gives:
  - C’: $\sqrt{1/3}\,|X>|\$>+\sqrt{1/3}\,|Y>|\$>+\sqrt{1/3}\,|Z>|{\sim}\$>$
- By branching indifference you are indifferent between C and C’:
  - C: $\sqrt{2/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\downarrow>|{\sim}\$>$
  - C’: $\sqrt{1/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\downarrow>|{\sim}\$>$
- Our question then reduces to:
  - Would you prefer game C’ or game D?

Unequal superpositions & symmetry

- Which game would you prefer to play in a branching multiverse?
  - C': $\sqrt{1/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\downarrow>|{\sim}\$>$
  - D: $\sqrt{1/3}\,|X>|\$>+\sqrt{1/3}\,|Y>|\$>+\sqrt{1/3}\,|Z>|{\sim}\$>$
- The only difference between C' and D is inessential labeling.
  - So you ought to be *indifferent* between these two games.
- But then you must be *indifferent* between:
  - C: $\sqrt{2/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\downarrow>|{\sim}\$>$
  - D: $\sqrt{1/3}\,|X>|\$>+\sqrt{1/3}\,|Y>|\$>+\sqrt{1/3}\,|Z>|{\sim}\$>$

Unequal superpositions & symmetry

- The rational agent must be *indifferent* between:
  - C: $\sqrt{2/3}\,|\uparrow>|\$>+\sqrt{1/3}\,|\downarrow>|{\sim}\$>$
  - D: $\sqrt{1/3}\,|X>|\$>+\sqrt{1/3}\,|Y>|\$>+\sqrt{1/3}\,|Z>|{\sim}\$>$
- But the only relevant physical feature C and D have in common…
  - that is, the only thing that could constrain rational credence…
- …is the fact that the *combined weight* of reward-branches is $\sqrt{2/3}$.
  - So the mod square of these weights quantify rational credence.
  - So probability (in a branching universe) is given by the Born rule.
- That's the Deutsch-Wallace proof!

What does this prove?

- That some rationality "axioms" entail branch weights constrain the credences of rational agents (who believe they live in a branching multiverse).
  - Now recall our analysis of probabilty:
    - (Objective) probability is that objective physical quantity that constrains rational *credence*.
    - Proof of the Born rule!

- But what if there are *other* ways of acting rationally?

- The proof only works if it rules out **all** other proposals for rational action...

Branch counting (2012: 190)

- **Description:** each branch is given an equal probability, so that if there are N branches following a particular experiment, each branch is given probability 1/N. Utility is then maximised with respect to this probability.

- **Rationale**: Each branch contains a copy of me; I have no reason to privilege any given copy.

- **Why it is irrational**:
  - Violates branching indifference and diachronic consistency
    - As we saw earlier.

The anything-goes rule (2012: 194)

- **Description**: Not a rule but a rejection of the need to have one: any transitive preference ordering over acts is rationally acceptable.

- **Rationale**: Everettian quantum mechanics is deterministic and we already have an acceptable deterministic decision theory: its only axiom is ordering.

- **Why it is irrational**: simply denies all the axioms?

The curl-up-and-die rule (2012: 194-5)

- **Description**: converse of anything-goes; not a rule but a claim to the effect that *no* rational strategy is possible in Everettian quantum mechanics.

- **Rationale:** (i) branch counting is a rational requirement, but its physically impossible, so rationality is impossible too; (ii) why bother trying to maximise the probability of a good outcome if the bad one happens too?

- **Why it is irrational:** unless there is something concretely wrong with the Born rule, there is no case to be made for the curl-up-and-die rule.

The fake-state rule (2012: 191)

- **Description:** The agent maximizes expected utilities as via the Born rule, but using a quantum state other than the physically real one.

- **Rationale:** None in particular, but is often intended to undermine the connection between the 'real' state and the physics.

- **Why it is irrational**: Violates state supervenience. It will assign different values to the same physical state.

The fatness rule (Albert 2015)

- **Description**: each branch is given a probability proportional to its quantum weight multiplied by the mass of the agent in kilograms (such that the total probability still equals one). Utility is maximized with respect to this probability.

- **Rationale**: Albert says (tongue in cheek) that an agent should care about branches where he is fatter because 'there is more of him' on that branch.

- **Why it is irrational**: it violates diachronic consistency: rational action takes place over time and is incompatible with widespread conflict between stages of an agent's life. In the case of the fatness rule, agents have motivation to coerce their future selves into dietary programs that they will resist!

- We will consider Albert's response (and other responses) on Thursday.

Thursday's lecture…

- We will (among other things) look at:

- David Albert's (2015) critique
  - To Papineau (general abstract objection)
  - To Wallace (technical (fatness measure) objection)
    - Primary reading

- Foad Dizadji-Bahmani's (2013) defense of branch counting.