14	Wed., 12/3 Fri., 12/5	**12.3-.5** Cats, Clones, and Zeno; Scholosauer – 7 Measurement Schloshauer Ch.3 – Interpretations, Ch. 12 Switching	**Daily 14.W** **Daily 14.F**
15	Mon., 12/8	**Review for Final** (comprehensive with emphasis on 5,6,8,12)	

Daily: Kyle Jacob Spencer Gigja Anton Jessica Sean Antwain Jonathan Casey Jeremy Mark Connor Brad

Equipment

- Griffith's text
- Elegance & Enigma
- Bohm's pilot wave analog - https://www.youtube.com/watch?v=nmC0ygr08tE
- "A Snapshot of Foundational Attitudes Toward Quantum Mechanics" – Maximilian Schlosshauer et. al.

Check dailies

Announcements
HW due next Tues (but welcome sooner)
Final: comprehensive with emphasis on most recent.

Daily 14.W Wednesday 12/3 Griffiths **12.3-.5** Cats, Clones, and Zeno; Scholosauer **7** Measurement

1. *Conceptual* : Summarize Scholosauer's 17 participant's main points about the Measurement Problem – what are the main perspectives? What do you find most or least compelling?
2. *Conceptual / Mathematical*: In your own words, why no clones?

12. Afterward

12.3 The No-clone Theorem

"Cloning" is giving another particle the exact same quantum state as your original particle has without 'measuring' the original particle. Griffiths suggests an application of cloning: If you make a lot of clones of one half of an entangled pair and measure a lot of the clones' spin alignments, then if they all return the same value, you can safely bet that the *other* half of the pair had been measured before you did the cloning, thus locking your half into a set state. Whereas, if you get a distribution of answers, you'll know that the other half had not been measured. In this way the person with the other half of the entangled pair would be able to communicate with you, potentially faster than the speed of light. Or so suggests Griffiths; of course, if you're a realist, you might imagine cloning not just what Quantum Mechanics could tell you about your system, but even the as-yet-unmeasured-but-existent properties.

The no-cloning theorem points out that, even if you *could* clone a simple state, you couldn't clone an entangled one. Cloning a simple state would look something like this:

$$\hat{C}\left(|\psi_1\rangle|X\rangle\right)=|\psi_1\rangle|\psi_1\rangle$$

overwriting some other state, X, with the original and desired state) and thus for some other original / desired state,

$$\hat{C}\left(|\psi_2\rangle|X\rangle\right)=|\psi_2\rangle|\psi_2\rangle$$

But then if you had a composite state, say

$$|\psi\rangle=\alpha|\psi_2\rangle+\beta|\psi_2\rangle,$$

Then, the cloning operation would return (if we assume that, whatever operation does the cloning, it's a *linear* operation)

$$\hat{C}\left(|\psi\rangle|X\rangle\right)=\hat{C}\left(\left(\alpha|\psi_1\rangle+\beta|\psi_2\rangle\right)|X\rangle\right)=\alpha\hat{C}\left(|\psi_1\rangle|X\rangle\right)+\beta\hat{C}\left(|\psi_2\rangle|X\rangle\right)=\alpha|\psi_1\rangle|\psi_1\rangle+\beta|\psi_2\rangle|\psi_2\rangle$$

Whereas what you would have wanted to have was

$$|\psi\rangle|\psi\rangle=\left[\alpha|\psi_1\rangle+\beta|\psi_2\rangle\right]\left[\alpha|\psi_1\rangle+\beta|\psi_2\rangle\right]$$

Example: Spin-x and Spin-z cloning

Here's an example of such cloning. Say you had a z-Stern-Gerlach machine, and electrons that were aligned with spin along the x axis were sent through it. Everyone that passes through the upper branch (for spin up) passes through another machine which spits out a second spin-up electron for everyone that comes through; ditto for the spin-down electrons taking the lower branch. Now, you have twice as many spin up and twice as many spin down, but if you try to recombine the beams, you won't get back definite x-aligned electrons.

> "Can we talk more about schrodinger's cat and what griffiths is talking about with the macroscopic system." Jessica

12.4 Schrodinger's Cat

The classic Schrodinger's cat thought experiment is that you lock a cat in a box with a vial of poisoned gas which is triggered to release when a single radioactive nucleus decays. You wait for the nucleus's half-life and then pause to wonder – what's the state of the cat, is it alive or dead?

Certainly your *knowledge* is that there's a 50/50 chance that the cat is alive/dead. So your *knowledge* would be represented by

$$|\psi\rangle=\tfrac{1}{\sqrt{2}}\left[|\psi_{alive}\rangle+|\psi_{dead}\rangle\right]$$

However, it's unfathomable that the cat is actually in some shadowy state of being. The most comfortable answer to this paradox is that a 'measurement', that is, an act which resolves a mixed quantum mechanical state into a definite state, is the act of its interacting with a macroscopic system. That interacting with a system of many variables locks in its own state. The process is known as "decoherence." The larger the system of interacting objects, the smaller the probability of significant fluctuations in state.

> Can we talk about decoherence and its implications?" Mark T,

I would also like to talk about this. What I got from footnote 15 of 12.5 is that decoherence occurs when a linear combination of distinct macroscopic states is possible, within a short amount of time, the wave function of a macroscopic object would revert back to its previous (classical) state and this is supposed to explain wave function collapse. Also, this explains when we measure something, the system evolves into something that we can experimentally observe...? I'm not sure. Gigja

Another vote for this. Bradley W

Decoherence: Here's an analogy: in statistical mechanics, if you have two interacting Einstein solids with very few members and very few units of energy, then there's a pretty broad distribution of possible energy distributions between the two solids. However, if you have even a modest number, like 100 oscillators in each solid, then the probability distribution gets *really* narrow, with the chance that the energy distribution is significantly different from 50/50 being negligibly small (though still not 0). Here's another, closer-to-home analogy: if you passed light through two slits, you'd get a broad peak in the middle, and weaker broad peaks on either side. If you added a third slit, you'd get the same pattern, except the peaks would be narrower/taller; if you added a fourth..thousandth…. had a whole diffraction grating, then you'd have *very* narrow peaks with a negligible amount of light falling between them. So the distribution goes from broad, continuous distribution extending between each of the peaks to discrete ones. Similarly, when you have *lots* of particles interacting, the composite, entangled wavefunction becomes very prominently peaked at the classically allowed values and there's negligible probability density at the mixed (cat's partly alive and partly dead) states. This is true for a composite system; similarly, when a quantum mechanical system (say, the spin of an electron in an entangled pair) is measured by interacting with a large, composite system (the measurement apparatus), it becomes 'entangled' with the apparatus, and that whole system tends to only the classical states and none of the mixed states. The fine print on this is that decoherence tells you that the probabilities for the mixed states are 'vanishingly small' but not that they indeed 'vanish.' So, for all practical purpose (FAPP), the weird mixed states vanish, but in principle they do remain.

"What causes the Zeno paradox? Some of the participants talk about decoherence. Could we go over this in more detail?" Spencer

I would like to go over this too. Jonathan

12.5 The Quantum Zeno Paradox

As just invoked with the cat, the collapse of the wavefunction from some mixed state with indeterminate values of certain properties to having a certain value, is central to Quantum Mechanics, but also outside of Quantum Mechanics – we have a tool for predicting the probabilities of the outcomes and time-evolving those probabilities, but we don't have a way of nailing down what they'll collapse too (though the study of decoherence is working on that). The Quantum Zeno Paradox / Watched-Pot Phenomenon is that a particle should be able to be held in an excited state indefinitely by observing it (presumably in such a way that doesn't 'rattle' it and inadvertently cause the decay). The mathematical argument is based on a chapter we haven't covered, so we'll have to take Griffiths' word for it that the probability of decaying from an excited state due to interacting with electromagnetic radiation is given by 9.39. Then, for very short times, the probability is

$$P_{a\to b} \approx \alpha t^2$$

So if you're able to observe (without otherwise disturbing) the state after a short time interval, then the probability of it's still being excited is

$$P_a \approx 1 - P_{a\to b} = 1 - \alpha t^2$$

And now that you've established it's in that state you observe after another short time interval, the chance that, after two observation intervals it's still in the excited state is

$$(P_a)^2 \approx (1 - \alpha t^2)^2$$

After *n* intervals, it's

$$(P_a)^n \approx (1 - \alpha t^2)^n$$

Then if we observe over a period of time T in intervals of size t = T/n, the probability is

$$(P_a)^n \approx \left(1 - \alpha (T/n)^2\right)^n$$

In the limit that *n* gets very large, that is, the observations become continuous,

$$(P_a)^n \approx 1 - n\alpha (T/n)^2 = 1 - \alpha T^2/n$$

So the second term vanishes for large *n* and the probability stays at 1.

In other words, a continuously observed system never decays.

It seems to me that there are two kinds of observations: destructive ones that would 'rattle' the system out of the excited state and constructive ones that would push the system back toward the excited state. In any event, the measurement / observation is a dynamic process, so the ability for continually fiddling with the system to prevent it from (or cause it too) transition seems reasonable.

"Can we talk about the different views on what a measurement means, axiomatic and so on?"Casey P,

I wasn't quite sure what was meant by axiomatic or axiom. I understand measurement by interaction but it is not clear to me what measurement by axiom is.Kyle B

I would assume that measurement by axiom would be the ideal result, and interaction is the experimental result. Thus when the two /should/ agree, it means that one would hope that the actual measurement matches your theoretical results.Bradley W

Question 7: The Measurement Problem

The quantum measurement problem: serious roadblock or dissolvable pseudo-issue?

Guido Bacciagaluppi

He starts off talking pragmatically about how to address or avoid the measurement question when exploring theoretical questions. Then he focuses directly on it: The measurement problem is just an aspect of decoherence when a simple quantum mechanical system interacts with its environment and thus enters into an entangled state with that environment. The more general question is how such a thing passes into the classical regime as it must – a well-defined value.

Caslav Brukner

The 'big' measurement problem is what a particular value (of the possible ones allowed for your system) is measured. The 'small' measurement problem is what mechanism leads to a measurement outcome at all.

The 'big' problem may be a mistaken question – it may simply be that things are irreducible probabilistic – there is no cause for one value rather than another. Alternatively, there are Bohm's hidden variables and Everett's many-worlds (which seem to me to still miss answering the *why* question.)

It may simply be axiomatic – an input to the quantum-mechanics model, and not justifiable *by* quantum mechanics.

An interaction that entangles the system's state with the apparatus's in a "macroscopically distinct state." Presumably, the process is not irreversible, though reversing may be impractical.

Jeffrey Bub

The problem of connecting probability with truth. Couches it in terms of "information-theoretic interpretation"; probabilities, knowledge, and information. He argues for considering the "information loss" that takes place during a measurement (strange to think of learning something as information loss, but reduces variables and possibilities) as a given, just-the-way-the-world-works kind of thing – more a matter of kinematics (just how things play out) than of dynamics (this step causes that step). He makes an analogy to Lorentz length contraction – we don't have a dynamic mechanism for it, it's just what happens when something moves faster and faster.

He too points to (and accredits to Pitowsky) the "big" and "small" measurement problems: the dynamic process by which individual measurements come about and the dynamic emergence of classical, Boolean probabilities for macroscopic measurements (the cat is alive *or* dead – not in a mixed state.) The "big" problem is a pseudo-problem if we're willing to accept that things are fundamentally probabilistic. The "small" problem is a consistency problem - we should be able to take account of decoherence as the system interacts with its complex environment and arrive at the classical probabilities.

Arthur Fine

He observes that the decoherence program - following the system's entanglement with the measurement device and with the larger environment – may, in the best case, cause rapid convergence to the extremely probable outcome (much like in statistical mechanics for large systems); however, there's still the question of – what pushes it over the edge from 'extremely probable' to 'actually happens'?

In a completely deterministic picture, which he argues the de Broglie-Bohm and many-worlds pictures really are since they both involve universal wavefunctions that are not interacting with anything else and thus fixed, while decisions appear to get made, events appear to happen, they're non-events in the sense that they were destined to happen all along. So, for those models, there isn't a discrete jump from before and after a measurement.

Christopher Fuchs

The measurement problem is "purely an artefact of a wrong-headed view of what quantum states and/or quantum probabilities ought to be." Look no deeper for meaning – we have probabilities, we measure, and determine the outcome. The probabilities needn't themselves reflect our imperfect knowledge of a deeper, richer (hidden variables) reality, nor need they be objective properties (pilot wave) themselves; they're just probabilities. He takes a very instrumentationalist / information / Bayesian position. The statevector (wavefunction) encapsulates our knowledge of the possible outcomes of a measurement and their probabilities; once you make a measurement, you have new information and you must update your statevector accordingly. "The state is a construct of the observer, not an objective property of a physical system."

Gian Carlo Ghirardi

More broadly, the problem is (as others have pointed out) not just about 'measurement' but the emergence of classical / macroscopic, objective outcomes from a probabilistic theory. He's dissatisfied with the largely verbal (rather than actually mathematical) way most options are treated – so it's a lot of philosophy and little physics. The theory doesn't have any obvious variables / properties that clearly demark the boarders between probabilistic and deterministic, reversible and irreversible.

- Consciousness. This was based on the idea that consciousness and physical happenings were fundamentally different – consciousness is supernatural (which is probably the most serious error any scientist can ever make – mark something off as 'supernatural', and thus not subject to scientific exploration).
- Decoherence. Allows that macroscopically distinguishable states can form a superposition, but the pure states are statistically very good approximations. He finds this repugnant; perhaps on the same grounds that Arthur Fine spells out – if we take it as simply a statement of probability, then we're still left with the question of 'what happens to tip the scales form probably will happen to actually has happened?' Alternatively, these aren't just probabilities but objective properties of the system and it really is in a mixed state (albeit one which is very strongly peaked.) That brings us back to a very mostly dead (but ever-so-slightly-alive) Schrodinger's cat. It also begs the question of, when you open the box, why do you experience an alive *or* a dead cat. So decoherence may move us from quantum to classical probabilities, but it doesn't move us the final inch from probabilities to definites.
- Statistical Ensembles. Some would argue that quantum mechanics doesn't talk about individual objects (and their objective properties?), just the statistics of ensembles of particles. However, that's been pretty-well disproven – single particles interfere with themselves.
- Decoherent histories. Unfortunately, his description is incomplete (assumes we know what he means by "histories.") In any event, he claims to have demonstrated that it doesn't work.
- Many-universes / many-minds. He finds it repugnant – not what "one ought to require from a scientific theory." He notes that it's been demonstrated that this approach can't explain the statistics of repeated measurements (so, all things happen in different

universes, but it's mute on why some things are more probable than others within one universe.)

- Modal interpretations. Something about recognizing even pure states as statistical combinations of mixed states, but then using the pure state for evolving the system?
- Bohmian. He sees it as the 'deterministic completion' of quantum mechanics (giving a mechanism underlying the statistical behavior) that gives results which are consistent with quantum mechanics. It resolves the measurement problem (since the particle really was a particle and really was somewhere with some property). (however, it doesn't give us a way of figuring out what the outcome will be – like statistical mechanics, there's an underlying determinism, but we can't work it out.)
- Collapse Theories. There's some mechanism that collapses the state for individual particles, but it's extremely rare for an individual particle in isolation. However, if a particle that's strongly interacting with another one collapses, it triggers the other's collapse too. So, the bigger the system of interacting particles, the more likely that one of them triggers the collapse for the whole system. (I wonder about how an object gets 'uncollapsed' – some time evolution back toward the mixed state.) He likes this theory because it gives a testable difference from quantum mechanics – a frequency of spontaneous collapse. He notes that a "mass-density" interpretation of collapse theories as strongly analogous to Bohm's picture.

Shelly Goldstein

If the wavefunction is an incomplete description of the system – so it communicates our incomplete knowledge, then its collapse upon measurement requires no explanation.
So, Quantum Information interpretations see no problem – the information we have changes when we make a measurement.
Similarly (or perhaps, for example) Bohm's model doesn't require explanation for the 'collapse' upon measurement – the particle actually had the value at the time of measurement (only we don't have a complete description of the pilot wave, so we couldn't predict what value that is.)
Copenhagen interpretation wouldn't see it as a problem either – we give the system the value when we measure – it didn't have that value before (but I have to wonder about after you measure – does it retain that value, does it now 'have' an objective property?)
If you insist on viewing the wavefunction as an objective property of the system, then that it dramatically changes upon measurement is indeed a problem to be addressed. He says that a strictly decoherence approach makes little sense because it seems to imply a "positivist" perspective (that the system really has a value, and you just don't know what) and decoherence just points out what that value is – so we're back to the wavefunction's representing limited knowledge rather than objective reality, and we're just using decoherence to improve our limited knowledge. So the measurement "problem" wouldn't be a philosophical problem for that camp. (though as someone else pointed out – there's still the question of how we move from 'highly probable' to 'actually happened' which decoherence can't address.)

Daniel Greenberger

Points out that randomness may be subjective. His example is that if you are measuring one of an entangled pair, not knowing that it's a part of an entangled pair, the answers you get appear random, but they are in fact correlated (however, I don't see why we would say it's both – so the outcome of the pair may be fixed while the outcome of a subsystem is random – similarly, the total energy in an isolated chunk of material may be set while an individual atom's allotment of that may fluctuate randomly.) What he takes from this is that decoherence is a "for all practical purposes" solution to the measurement problem, but not a fundamental solution – you never know whether a measurement is 'done' or you've just entangled more particles (your measurement device) with the object.

Lucian Hardy

Some call it the "reality problem" – the door is *really* open or closed, not open and closed. So, how do we move from probability to certainty? The reality problem stems from believing that the wavefunction describes the "ontological" state of being of the system, rather than our state of knowledge of it. I think he says that the problem goes away if we don't insist that the state of the system evolves in a way that depends on its prior state (that is, if the state at time t+dt is unrelated to the state at time t).
He's not satisfied with pilot-wave, many-worlds, or collapse models. An instrumentalist (or information-theory) approach merely sidesteps, but does not resolve the question – they simply don't presume to speak about any underlying reality. He believes (but recognizes that it is merely a belief) that solving quantum gravity will solve this problem.

Anthony Leggett

It's a real problem. Look to experimental evidence for judging interpretations that might resolve it.

1. Two-slit experiment: that the probability distribution when both slits are open is not the sum of the probability distribution when one or the other is open demonstrates that the system really interacts with both / doesn't just choose one or another (he more strongly says that 'each individual atom' rather than 'the system'). Pilot-wave notions feel like word games to him, and don't really solve the underlying measurement problem, just shift the question slightly.
2. Quantum Mechanics simply has non-zero probabilities for both paths.

Shouldn't this scale up to include dead/alive cats? Decoherence may make it difficult to detect the interference of the two states, but they should be there by the quantum mechanical model (back to Decoherence points the way toward a definite, but still leaves us in the realm of 'quite probable', not 'has happened.')

Tim Maudlin

He seems to think that there are "several theories" that don't have measurement problems (everyone else seems to shoot down all theories as flawed in some way). He too seems to point to this as a reality / interaction problem – we should be able to account for what happens in an interaction whether we call that interaction a measurement or not.

David Mermin

It's a pseudo-problem in that it's not completely resolved, but it's not a major roadblock either. There's the mistaken problem of why there's a discontinuity in the time evolution of a wavefunction when a measurement is made. This is mistaken because folks reify (attribute ontological properties to) the wavefunction rather than recognizing it as a representation of our state of knowledge. He says he mostly, but not completely buys this.
The other 'measurement problem' is a question of whether 'macroscopic states' display interference between states that describe different observational outcomes – the classic "cat

states." If that interference is merely very small (due to decoherence), that's one thing, but if it's completely gone, then there's a real problem of understanding how it came to vanish.

Lee Smolin

A sign that the quantum theory is not fundamental, and that we must search more for a more fundamental theory.

Anthony Valentini

He dismisses the quantum superposition of 'cat states' question, though does so by appealing to a statistical interpretation (which is undermined by the presence of self-interference of an individual particle.) He asks a complementary question – what happens to "macroscopic realism" as we scale down to microscopic systems? He insists that there can't be a smooth transition from indefinite to definite (but I wonder how definite anything practical is – the direction a pointer on a dial points is still a bit fuzzy on the microscopic scale, but quite definite enough on the macroscopic scale.)
He dismisses 'shades of real' (but again, I worry that he's not thinking specifically enough – give me a well-formulated question, and the answer I expect you'll get back from quantum mechanics will be quite satisfactory for a macroscopic system.)
He dismisses the notion that reality is dependent on perspective – no change in perspective would change the readout on an apparatus' display.
He dismisses redefining logic – if you don't like the answer logic gives you, it's a weak argument that logic is broken.
He dismisses abandoning objective reality at the macroscopic level – people exist, chairs exist… If we accept the reality of these things, we must accept that some type of reality exists on the microscopic scale as well. (there's reality, and then there's stability)
He dismisses the instrumentationalist / information-theory position as a cop-out: in everyday life we consider things real, to avoid doing so at the microscopic scale is to avoid a major issue – there must be some kind of reality down there, and our job is to try to understand it.

David Wallace

Roadblock though it may be at present, hopefully it will be dissolved into a pseudo-problem when we gain the right perspective, just as many other major roadblocks have done in science. Maybe the question isn't 'why don't we see the macroscopic world as a superposition of states' but 'what would the macroscopic world look like if it were in a superposition of states; is that what we see?' Now, the cat's being alive and dead is no longer a paradox, it's a problem to be tackled with decoherence for large, open systems and an Everettian approach (many possibilities coexisting.)

Anton Zeilinger

Quantum information perspective – not a problem with quantum mechanics. (the folks who say this may be making the subtle distinction between something's being a problem to be figured out and being a problem with Quantum Mechanics – if you don't expect quantum to do anything but manage knowledge, well it does that just fine; but what's left glaringly open is that we don't have a theory that models reality, and that's then the problem.)

Wojcrech Zurek

Many worlds and the Copenhagen interpretation are cop-outs. Decoherence needs to be seriously worked out to try to tackle the transition from quantum to classical in general (not just focusing on measurement). In spite of Decoherence's progress, there's still the question of how information/knowledge/probability relates to existence/reality/certainty.