Philosophy of quantum mechanics

VU University Amsterdam: W_MASP_TF013 Lecture 10: 5/3/2015
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Today's lecture

- Recap: GRW and the tails problem
- An odd consequence of GRW theory
  - Experiments with television screens
- Triggered collapse theories
  - Can they meet the three constraints?
- CCC-theory: consciousness causes collapse
- Objections to CCC-theory
  - Albert's objection
  - Kosso's objection
  - Butterfield's objection
  - Loewer's objection
  - The quantum Zeno effect
  - The tails problem

Research essays – example questions

- Many worlds theory
  - Probability problem
    - Is Papineau's defence adequate?
    - Is Albert's critique convincing?
    - Does the Deutsch-Wallace proof work?
- Spontaneous collapse theory
  - Tails problem
    - Does Albert solve the problem?
    - Does Chalmers solve the problem?
    - Does Lewis solve the problem?
- Triggered collapse theory
  - Dynamics problem
    - Have Chalmers and I adequately responded to critics?
    - Can triggered collapse theories solve the Zeno problem?
    - Can consc-causes-collapse theory solve the tails problem?

Recap: GRW and the tails problem

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).**
    - Collapse theories deny B.
    - The matter-density version of GRW also denies A.

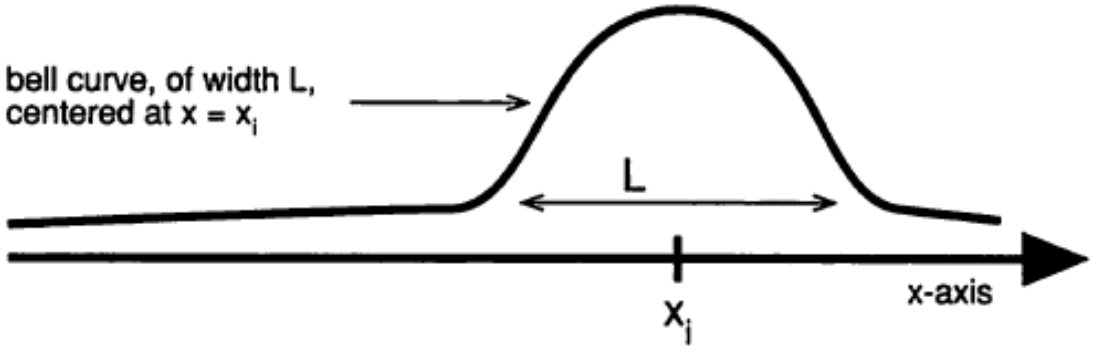
  - C. Measurements always (or at least usually) have determinate outcomes, i.e., at the end of the measurement the device indicates a definite physical state.

Spontaneous collapse: the basic idea

- Definite measurement outcomes are guaranteed by the form of the collapse hypothesis:
- **Collapse hypothesis**: elementary particles have a small probability per unit of time for collapsing into a definite *position*.
- Measuring devices are composed of many *entangled* particles and so have a high probability per unit time for collapsing into a definite position.
- The probability that a measuring device will collapse into one of its superposition components is given by the (modulus) square of its coefficient – the theory therefore recovers Born rule predictions.

The GRW collapse function

- GRW postulate two new fundamental constants of nature.
  - 1. The probability per unit time for spontaneous collapse.
    - Particles have a 10^{-16} probability per second for collapse.
  - 2. The width L of the bell curve:
    - $L = 10^{-5}$ meters.



The tails problem

- Consider a familiar device-electron entangled state:

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

- This state is unstable.
  - An elementary component of m is bound to spontaneously collapse and so collapse everything it's entangled with.

- But are we guaranteed a measurement outcome just by spontaneously "collapsing" it to this state:

$$\sqrt{1-\alpha^2}|"hard" >_m |hard >_e + \alpha|"soft" >_m |soft >_e$$

- Where α is very small but nonzero?

The *structured* tails problem

- If the collapse centre structure determines a particle configuration, then so do the structures in the tails.
- This is because the tails and the collapse centre are structurally isomorphic (or at least relevantly structurally similar).
- Nothing about low mod-square value can suppress this isomorphic structure.
- The consequence is an Everettian many-worlds ontology!
  - I will make the formulation of the problem more precise after considering some proposed solutions.

Proposed solutions

- 1. Clifton and Monton's response
  - We can take high objective probability to mean *existence*.
- 3. Tumulka's and Albert's responses
  - The "matter" in the tails is noise and does not have structural credentials to compose macro-objects.
- 4. Monton's and Chalmers' responses
  - Experiences are only determined by "high weight" brains.
  - "Being located at X" means "being reliably disposed to cause experiences as of being located at X."
- 5. Lewis' response
  - GRW should reject functionalism and Dennett's criterion.

Clifton and Monton's response

- Recall Wallace's symmetry objection...
  - Why should "high amplitude" rather than "low amplitude" be existence determining?
- These amplitudes are related to objective probabilities through Born's rule. Can a solution be found there?
  - "If one is willing to entertain the thought that events in a quantum world can happen without being mandated or made overwhelmingly likely by the wavefunction, then it is no longer clear why one should need to solve the measurement problem by collapsing wavefunctions! [...] one supposes there to be *a plausible intuitive connection between an event's having a high probability according to a theory, and the event actually occurring*".
    - Clifton and Monton, In "Losing your Marbles in Wavefunction Collapse Theories" 1999, p708.

Problems

- Problem 1: existence and probability don't line up?
  - Is the "plausible, intuitive" connection supposed to hold between *high probability* and *high* ***degree*** *of existence*?
  - But presumably existence does not come in degrees.
  - A connection between existence (simpliciter) and high probability seems more arbitrary than intuitive.
- Problem 2: The roles of probabilities are being confused?
  - The mod-square of a superposition component is the objective probability *for that component to become a collapse centre*.
  - It isn't *also* the objective probability for that component to have 'actually occurring' status.
  - On a realist view of GRW that component *already* exists.

Tumulka's and Albert's responses

- Tumulka & Albert consider the "matter-density" version of GRW...
  - High-amplitude branches determine matter in 3D space.
  - Defined by the "matter-density function" – a function from mod-square amplitudes to matter distributions.
- Tumulka's example...
  - Take a marble in a superposition of being inside the box (with high density) and being outside the box (with low density).
    - The low density matter is analogous to "vapour" hence marble is inside the box.
- Problem:
  - But the "vapour" is structured like a marble!
    - Compare: Schrödinger's cat.

Albert's billiard balls example

- **Ball 1**: superposition of travelling to point P and to point Q, from the left.
- **Ball 2**: superposition of travelling to point P and to point Q, from the right.
  - Prior to collision:
    - **Ball 1**: $a|{\rightarrow}P{>}_1 + b|{\rightarrow}Q{>}_1$
    - **Ball 2**: $a|P{\leftarrow}{>}_2 + b|Q{\leftarrow}{>}_2$
  - After collision:
    - $a^2|\leftarrow P{>}_1|P{\rightarrow}{>}_2 \; + \; b^2|\leftarrow Q{>}_1|Q{\rightarrow}{>}_2 \; +$
    - $ab|Q\rightarrow{>}_1|\leftarrow P{>}_2 \; + \; ab|P\rightarrow{>}_1|\leftarrow Q{>}_2$
  - Here, $a^2|\leftarrow P{>}_1|P{\rightarrow}{>}_2$ is the high density component in which two billiard balls are travelling away from P.

Albert's billiard ball example

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  - $a^2| \leftarrow P>_1|P\rightarrow>_2 \; + \; b^2| \leftarrow Q >_1|Q\rightarrow>_2 \; +$
  - $ab|Q \rightarrow >_1| \leftarrow P>_2 \; + \; ab|P\rightarrow >_1 | \leftarrow Q >_2$
- Here, $a^2| \leftarrow P>_1|P\rightarrow>_2$ is the high density component in which two billiard balls are travelling away from P.

- "But look at the low-density sector: what happens there is that two balls converge at Q and pass right though one another – and (in the meantime) two new balls appear, which then recede in opposite directions" (2015: 154).
- So only high-density matter composes familiar stuff.

Problems

- If there is no reason to distinguish between distinct low-density sectors then Albert is right.

- But decoherence entails that in realistic circumstances there must be distinguishable sectors within the low density sector.
  - These will be (to varying degrees) dynamically isolated from each other (despite overlapping in space).

- When we make these distinctions we rediscover structured tails.

Monton's and Chalmers' solution

- "A certain assumption about psychophysical parallelism needs to be made. But the assumption is a reasonable one. […] There is no reason to suppose that mental states supervene just on particle location; instead we can suppose that mental states supervene on the distribution of [matter]. Since **the masses of particles in a brain are concentrated in the appropriate regions** of space, it is reasonable to assume that **the appropriate mental states supervene on those mass concentrations**"
  - Bradley Monton (2004:418).

Monton's and Chalmers' solution

- "In the case of macroscopic spatial properties, it is plausible that **spatial properties can be picked out by spatial concepts as that manifold of properties that serve as the causal basis for spatial experience** [...] To simplify, the property of being two meters away from one might be picked out as the spatial relation that normally brings about the experience of being two meters away from one. [...] One can then argue that on a collapse interpretation, **the properties and relations that normally bring about the relevant sort of spatial experiences are precisely properties and relations requiring the wavefunction's amplitude to be largely concentrated in a certain area**."
  - David Chalmers, In "Constructing the World" (2012: 295-296).

Problems

- Where A&L postulated that...
  - "Particle p is in region R" if and only if the mod-square value of p's quantum state associated with points in R is high."
- Chalmers adds...
  - "Particle p is in region R" if and only if **the fact that** the mod-square value of p's quantum state associated with points in R is high, **is the primary cause of experiences of particle p being in region R**.
    - For particles big enough to cause experiences, that is! We can then extrapolate to smaller components.
- Is this a good analysis of our physical concepts?
  - Chalmers argues that our disposition to apply spatial concepts in certain matrix-like scenarios supports the analysis.
    - http://web.ics.purdue.edu/~drkelly/ChalmersMatrixMetaphysics2001.pdf
- Even if so, doesn't GRW now need substantive psychophysical principles to make the causation claim come out true?

Lewis' solution

- The GRW theory requires that we reject the principle that Everettians use to derive worlds from wave-functions.
- The principle is Dennett's criterion.
  - Roughly: emergent objects can be seen as *patterns* in the underlying microphysics.

- GRW must reject this very intuitive principle.
- But Everettians have to reject the very intuitive principle that probability doesn't require uncertainty.

Problems

- Our formulation of the structured tails problem does not appeal to Dennett's criterion, or any emergence criterion. The assumptions are:
  - (i) If the collapse centre and the tails exhibit sufficient structural isomorphism then, if the collapse centre (or the tails) determines a macro-structure then the collapse centre and the tails determine structurally isomorphic macro-structures. [Supervenience principle]
  - (ii) If it is not the case that mod-square values explain differences in the macro-structures then the collapse centre and the tails exhibit sufficient structural isomorphism. [Explanation as our guide to supervenience]
  - (iii) It is not the case that mod-square values explain differences in the macro-structures. [As argued]
  - (iv) Hence, if the collapse centre (or the tails) determines a macro-structure then the collapse centre and the tails determine structurally isomorphic macro-structures. [From (i) to (iii)]

Problems

- (iv) Hence, if the collapse centre (or the tails) determines a macro-structure then the collapse centre and the tails determine structurally isomorphic macro-structures. [From (i) to (iii)]

- To derive (iv) we don't assume that GRW determines *any* macro-structure let alone a multiverse structure. For that we need a principle from GRW:

  - (v) The collapse centre determines a macro-structure. [GRW principle]
  - (vi) Hence, the collapse centre and the tails determine structurally isomorphic macro-structures. [From (iv) and (v)]

Two (further) tails problems

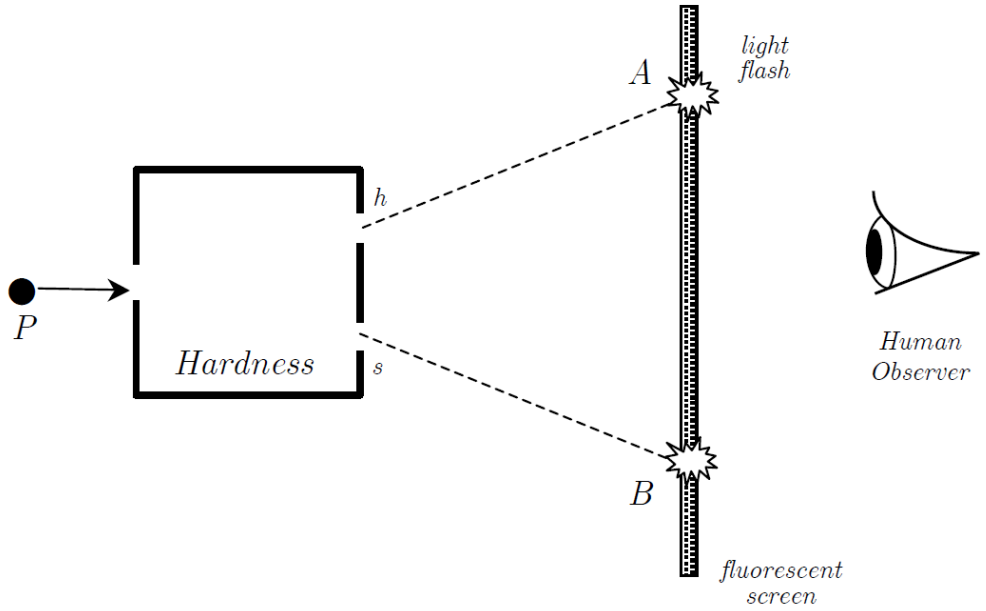
- 3. The multiverse tails problem
  - Assuming the structured tails problem is unsolvable: collapse actually has distinct effects on tail-worlds: they become overwhelmed by radiation.
    - **We ignore this problem:** we want to know *whether* the structured tails problem is solvable.

- 4. The tails dilemma
  - Changing the Gaussian function into a function with compact support introduces conflict with relativity theory.
    - **We ignore this problem:** we want to know *whether* the GRW collapse function needs to be changed.

An odd consequence of GRW theory

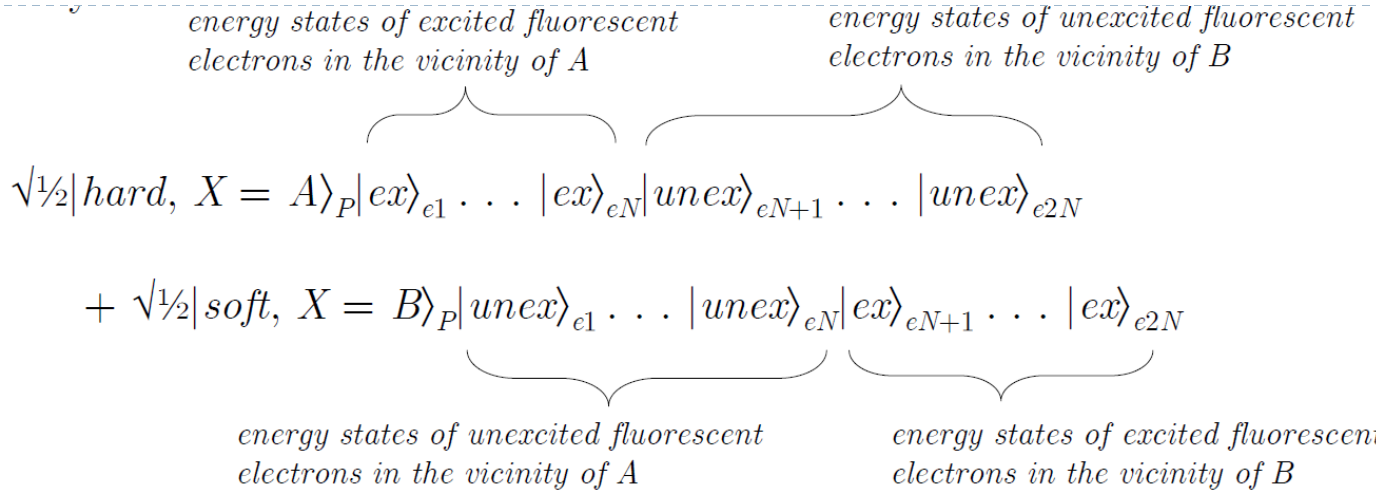
Experiments with television screens

- Albert (1992: ch 5) raises a curiosity...
  - What about measurement outcomes not indicated by the *positions* of things?
    - Example: TV screens illuminate to indicate detection of incoming particle P, not by changing spatial position but by changing energetic atomic states.
    - So: measurement outcome *without* position entanglement?



Set-up: To measure *Hardness* of P, insert it into *Hardness* box. If it's *hard*, it will exit at h and impact screen at A. If it's *soft*, it will exit at s and impact screen at B.

Experiments with television screens



- P's position is entangled *not* with the *positions* of the screen-electrons, but with their *energies*.
- The excited electrons emit photons such that:
  - "there literally fails to be any fact about whether (say) Ralph Kramden's face or Ed Norton's face is the face that appears on some TV screen" (Albert 1992: 104).
- Ghirardi (et. al.): such outcomes will inevitably be recorded in the positions of brain states.
  - Albert worries that this comes too late in the measurement process.
  - Albert then considers surgically removing those brain states and replacing them with states that register the result but not in the positions of neurons!
- Make of this what you will...

Triggered collapse theories

Basic idea

- There are certain special properties that collapse superposition states into definite states.
- Presumably: properties that cannot themselves superpose – "determinate-properties" or "d-properties".
  - Collapse occurs when superposed systems interact with systems that have the d-property.
  - The d-property refuses to superpose in accordance with the usual linear dynamics.
  - In doing so, the d-property collapses the superposition of the other system.

D-properties: some (vague) suggestions

- 'Being conscious' as a d-property?
  - Albert objects:
    - 'Conscious' is as vague as 'measurement'.
    - Requires a radical mind-body dualism.
  - We will come back to this.

- Other vague proposals: 'macroscopic', 'recording', 'meaning' (etc. see note 5 page 84 of Albert).

- The collapse mechanism must be *precisely* specifiable.

D-properties: non-vague suggestions

- Think of any non-vague property...
  - Having an exact location.
  - Having mass or having such and such mass.
  - Being a white electron.
  - Being composed of exactly three million elementary particles.
  - Etc.

- We need some constraints to rule some of these suggestions out.
  - The constraints are the same as for spontaneous collapse theories...

Constraints on D-properties

- General constraints for collapse hypotheses:
  - **Constraint 1**: Guarantee that measurements have specific outcomes.
    - Collapse must avoid macroscopic superpositions such as superpositions of measurement devices.
  - **Constraint 2**: Guarantee that measurements have outcomes *with the right probabilities*.
    - However constraint 1 is met, it must be that the relative frequencies of measurement outcomes correspond to Born's rule.
  - **Constraint 3**: Guarantee consistency with experiments on isolated particles.
    - We know that most properties of isolated particles enter into superpositions.

Constraining the options

- Constraint 3 rules out many options:
  - Position
    - Double-slit experiment demonstrates position superposition for objects at least as large as bucky-balls (made of 60 carbon atoms).
  - Colour / hardness / gleb / any spin-space property
    - Three-box experiment, 2-path experiments demonstrates superpositions of these properties.

- Constraint 1 does too:
  - Being located at region R (a tiny region to the left of Pluto's current position).

Remaining options

- Options that haven't been proposed:
  - Compositional properties
    - Being made of *this* many particles, or this many of *these* kinds of particles.
  - Configurational properties
    - Being configured in a certain shape.
  - Informational properties
    - Having an amount of information integration larger than a certain threshold (e.g. Tononi's phi).
- Options that have been proposed:
  - Mental properties
    - To be considered next.
  - Spatiotemporal properties
    - Briefly considered at the end.

Consciousness causes collapse

Why consciousness?

- Let's first consider why consciousness might be a plausible d-property...
  - 1. Saves the key datum expressed in proposition (C) in the most straightforward way.
  - 2. Potentially explains collapse rather than just postulating it.
  - 3. Consistency with independently plausible (albeit controversial) arguments for the irreducibility of consciousness.
  - 4. Contributes to a solution to the causal problem (what does consciousness actually *do*?)

Determinate measurement datum

- Proposition (C) concerns the challenge of recovering determinate measurement *outcomes*.
  - We've seen that GRW does not obviously achieve this.
    - The structured tails problem.
  - Everett theories analyse superpositions of measurement outcomes in terms of bifurcation of measurement outcomes.
- This problem is *automatically* solved in CCC.
  - The basis of the theory is determinate experiences (e.g. of determinate measurement outcomes).

Explaining collapse

- GRW does not explain why collapses occur, but just postulates them.
- But arguably, CCC can explain why collapse occurs.
  - It may follow from the very nature of consciousness that consciousness cannot be superposed.
  - Unlike position and spin etc. we arguably cannot conceive of superposed conscious states.
    - The difference being we have direct introspective access to consciousness that justifies our ruling out this possibility.
  - So: the nature of consciousness may explain why the linear dynamics must break down.

Independent evidence for dualism

- Reductive explanations of consciousness seem impossible:
  - Any physical basis proposed for the explanation of consciousness seems consistent with the absence of consciousness.
    - The "hard problem of consciousness".

- Many take this to support mind-body dualism.
  - This would provide independent support for an extra-physical element that intervenes on physical evolution.
  - This would in turn provide independent support for CCC.

Potentially solves the causal problem

- No-one has a clear idea of exactly what consciousness does.
- CCC provides a (clear?) answer to this problem, by stating the exact causal role of consciousness (collapse).

- But what if we can simply treat consciousness as another quantum system that obeys the extra constraint of being determinate, and so collapses the wave function?
  - Measurement problem *and* mind-body problem demystified at once?

The basic idea of CCC-theory

- Purely physical systems are governed by the linear, deterministic, dynamical laws.
- These laws are supplemented by "psychophysical laws" connecting physical systems to consciousness in both directions:
  - Physics-to-consciousness direction:
    - Laws specifying that certain physical (e.g. brain) states determine certain conscious states.
    - E.g. Some complex physical property P is lawfully associated with consciousness and different values of P determine different conscious states.
  - Consciousness-to-physics direction:
    - The collapse law specifying how impending superpositions of consciousness resolve probabilistically into definite conscious states and associated wave function collapse.

Physics-to-consciousness laws

- Laws specifying that certain physical (e.g. brain) states determine certain conscious states.
  - How does this work?
- Options:
  - Whenever brain state |Bi> obtains, associated conscious state |Ci> obtains.
    - Problem: aren't these brain states vaguely specified?
  - Whenever microphysical state |Mi> that realises brain state |Bi> obtains, associated conscious state |Ci> obtains.
    - Problem: isn't it sometimes indeterminate whether |Mi> realises |Bi>?
  - We may need to precisely delineate specific quantum states |M1> to |Mn> *of the type* that realise brain state |Bi> to formulate a physics-to-consciousness law for |Ci>.

Consciousness-to-physics laws

- The physics-to-consciousness laws are a set of laws of the form:

$$|B_i > \rightarrow |C_i >$$

  - This says: physical state i (which realizes brain state i) lawfully determines conscious state i.

- The linearity of the dynamics then entails:

$$\#|B_i > + \#|B_j > \rightarrow \#|C_i > |B_i > + \#|C_j > |B_j >$$

- The consciousness-to-physics laws intervene right before consciousness superposes and instead gives:

$$|C_i > |B_i > with\ probability\ |\#|^2\ OR$$

$$|C_j > |B_j > with\ probability\ |\#|^2$$

Objections to CCC-theory

- Albert's objection
  - 'consciousness' no better than 'measurement'.
- Kosso's objection
  - Exploits the mind-body problem without contributing a solution.
- Butterfield's objection
  - What consciousness collapses has not been specified.
- Loewer's objection
  - On CCC-theory, consciousness cannot have evolved.
- Chalmers' concern
  - What to say about the quantum Zeno effect?
- My concern
  - Does the theory suffer a tails problem?

Albert's objection to CCC-theory

- 'consciousness' has no precise meaning...
  - "But the trouble here is pretty obvious too: What this "theory" predicts (that is: what "theory" it is) will hinge on the precise meaning of the word conscious; and that word simply doesn't have any absolutely precise meaning in ordinary language." (p83).

- Two questions:
  - Is 'consciousness' ambiguous?
    - Can we *disambiguate* it then?
  - Is 'consciousness' vague?
    - Is there a *precise* disambiguation?

Access vs phenomenal consciousness

- An important distinction** in consciousness science:

- A mental state is ***access conscious*** if:
  - ...the information it carries is generally available for use and guidance by the system, e.g. if the information in the state is made available to memory, imagination, can be reported etc.

- A mental state if ***phenomenally conscious*** if:
  - ...there is something it is like for the system to be in that state. (Think: what is it like to see red, to feel happy, to have an itch?) These states are the subjective qualitative aspects of experiences or "qualia".

    - **Introduced in: Block, N. (1995). "On a Confusion about a Function of Consciousness". *Behavioral and Brain Sciences* 18 (2): 227-287.

Access vs phenomenal consciousness

- Is "access consciousness" vague?
  - Could there be a borderline case of an access conscious state?
    - A mental state only made available to subconscious long term memory?
    - A state within a laptop that the laptop can report on its screen?
- Is "phenomenal consciousness" vague?
  - Could there be a borderline case of phenomenal consciousness?
    - Phenomenally conscious states can come in degrees (e.g. degrees of pain, happiness etc.) but hard to imagine a borderline case of a phenomenally conscious state (e.g. of pain simpliciter).
- CCC can appeal to phenomenal consciousness in response to Albert.

Experimental precision?

- CCC-theory predicts that consciousness causes collapse.
- Collapse is a real physical event with (in principle) empirically testable consequences.

- Can CCC-theorists just say that consciousness is precisely defined (or is 'precisified') by experiment: by determining exactly when and where collapse occurs?

Kosso's objection

- "The important interaction between mind and matter is unexplained. There is no clue as to the mechanism by which consciousness affects physical objects and causes the collapse of the state function. The consciousness interpretation does not offer progress since it explains one mysterious phenomenon (the collapse of the state function during measurement) in terms of an equally mysterious phenomenon (the interaction between mind and matter)."
  - Peter Kosso. In *Appearance and Reality: An Introduction to the Philosophy of Physics*, p171.
- Response: what if the consciousness interpretation makes the mind-matter interaction less mysterious?

Butterfield's objection

- Butterfield points out that the physical time and place of collapse has not been specified.
  - So let's try to specify it.
  - Let N be the state of the *neural correlate of consciousness*.
  - Let R be the state of the retina of the observer.
  - Let M be the state of the measurement device.

    - T_1: $|ready\rangle_N |ready\rangle_R |ready\rangle_M (\#|\uparrow\rangle + \#|\downarrow\rangle)_e$
    - T_2: $|ready\rangle_N |ready\rangle_R (\# |\uparrow\rangle_M |\uparrow\rangle_e + \# |\downarrow\rangle_M |\downarrow\rangle_e)$
    - T_3: $|ready\rangle_N (\# |\uparrow\rangle_R |\uparrow\rangle_M |\uparrow\rangle_e + \# |\downarrow\rangle_R |\downarrow\rangle_M |\downarrow\rangle_e)$
    - T_4: $|\uparrow\rangle_N |\uparrow\rangle_R |\uparrow\rangle_M |\uparrow\rangle_e$
      - Or: $|\downarrow\rangle_N |\downarrow\rangle_R |\downarrow\rangle_M |\downarrow\rangle_e$) with Born rule probabilities.

The neural correlate of consciousness

- Can we specify the neural correlates of consciousness?
  - A topic for neuroscience.
- Perhaps our best bet given current neuroscience is:
  - When the physical realizers of brain states exhibit high enough *integrated information*, they *determine* consciousness.
    - Determination could also be replaced with coupling (to a pre-existing field of consciousness).
  - For more on information integration theory see the work of Tononi.
    - http://www.biolbull.org/content/215/3/216.full

Loewer's ("fatal") objection

- "The quantum state of the early universe was not an eigenstate of consciousness. But if the state of the early universe evolved by Schrödinger's law it would *never* result in a state that is an eigenstate associated with the existence of conscious observers. The problem is that the first collapse requires the existence of a conscious observer but the existence of a conscious observer requires prior collapses of states. CCC can't get started."
  - Barry Loewer, In "Consciousness and Quantum Theory."

Loewer's solution?

- "I can think of a modification of [CCC] that might be thought to handle this problem. Suppose that whenever the state is a superposition of states that include states that support consciousness, that state collapses into one of its components.

- A consequence of this solution:
  - "With this modification as soon as the state of the universe is such a superposition a collapse occurs and there is some chance that the collapse will produce a state in which there are conscious beings."
- Is this a bad consequence?

Loewer's objection

- "The trouble is that it probably entails that collapses occur too early in the history of the universe and too often. It is very likely that the state of the early universe was such a superposition. If that is so then collapses would occur during the early universe at a rate contrary to what we know."
- Responses:
  - Why is it very likely that a superposition component of the early universe contains observers?
  - Even if there were, what is it that "we know" that is contrary to early collapses?

The quantum Zeno effect

- Provably, if a physical system is continuously measured then it will *freeze*.
  - This has also been found by experiment.
    - http://en.wikipedia.org/wiki/Quantum_Zeno_effect#Experiments_and_discussion
- The collapse postulate instantaneously flicks the state vector to a basis vector.
  - Where the basis is given by the operator being measured for.
- The Schrödinger dynamics continuously rotates the state vector
  - No sudden jumps to basis vectors.
- Now imagine two collapses in quick succession.
  - The second collapse will almost certainly put the state vector back to wherever the first collapse put it.
- Now imagine a continuous infinity of collapses.
  - All motion stops.

Two Zeno problems for CCC-theory

- **Problem 1**: If the state of consciousness is represented by a state vector, then how does consciousness evolve from one definite state to the next – how are superpositions avoided?

- **Problem 2**: the brain may be being superposed (via magnification) often enough to trigger the quantum Zeno effect in the brain.

QZE problem 1

- **Problem 1**: If the state of consciousness is represented by a state vector, then how does consciousness evolve from one definite state to the next – how are superpositions avoided?

  - **Potential solution**: the physics-to-consciousness laws must *correlate* continuous changes of consciousness with continuous *coarse-grained changes* in the brain.

  - **Implication**: consciousness (unlike the brain) is not a quantum system. The theory is irreducible *dualistic*.

QZE problem 2

- **Problem 2**: the brain is being superposed often enough to trigger the quantum Zeno effect in the brain.
- Magnification = the process that would lead to branching if not for collapse.
- Magnification may be ubiquitous, but not obviously continuous!
- Without more exact details of the extent of magnification it's hard to know if this is a problem.

Does CCC-theory have a tails problem?

- Mathematically, consciousness must multiply the brain's wave-function by *some* function.
  - Which function? Recall:
    - T_3: $|\text{ready}\rangle_N (\# |\uparrow\rangle_R |\uparrow\rangle_M |\uparrow\rangle_e + \# |\downarrow\rangle_R |\downarrow\rangle_M |\downarrow\rangle_e)$
    - T_4: $|\uparrow\rangle_N |\uparrow\rangle_R |\uparrow\rangle_M |\uparrow\rangle_e$
      - Or: $|\downarrow\rangle_N |\downarrow\rangle_R |\downarrow\rangle_M |\downarrow\rangle_e)$ with Born rule probabilities.
  - How to get from T_3 to T_4?
- Primary constraint:
  - The collapse must put the brain into a (coarse grained) definite state (but superpositions of other structures are fine).
  - Seemingly lots of complicated options, but no obvious simple options (as with GRW's simple Gaussian).

Roger Penrose's theory

- The problem of quantum gravity:
  - Quantum mechanics does not let space or time enter into superpositions, rather, superpositions evolve *in* space *over* time.
  - But in general relativity spacetime structure itself transforms in response to mass. This variation in spacetime structure explains gravity.
  - There is no agreed upon solution to the problem of finding a unified theory of "quantum gravity".
- Roger Penrose tried to solve this problem and the measurement problem at once!
  - Spacetime triggers collapse when superpositions of mass-eigenstates try to superpose spacetime structure.
  - Unfortunately, Penrose had to allow for some superposing of spacetime structure, and so instead proposed a superposition threshold as the trigger.
  - But this brings back the problem of quantum gravity.
    - See Shan Gao's "Does gravity induce wavefunction collapse? An examination of Penrose's conjecture" (and references therein).