Loopholes

Experimental loopholes
Metaphysical loopholes

Simulation Model Challenges

Gill - Accardi 2001
Vongehr: Quantum Randi Challenge
Gill - Christian 2019

Loopholes:
experimental loopholes

By definition, experimental loopholes are closable by careful experimental precautions

However, the effectiveness of those precautions might be subject to metaphysical objections

Detection Loophole

- Photon polarization: not all photons actually arrive
- Outcomes are actually ternary: horizontal, vertical, non-detection
- If QM is true, and we would use usual optimal states and measurements, and detection is completely at random (and independent at the two measurement stations), we would need at least 82% detector efficiency before we could violate a Bell inequality

Coincidence loophole

- We don’t predetermine times of *emission* of photons
- Two detections in each wing of the experiment are considered a pair, if they arrive at times less than some prechosen time interval (“the coincidence window”) delta apart

Solution to coincidence loophole

- Use a pre-fixed lattice of time-slots of width delta

- Use a martingal test (ie count only those time slots when there is one detection in both wings)

Solution to detection loophole

- In photonics experiments, we now have photo-detectors with 75% efficiency

- It turns out that we can violate Bell provided we go to different states and measurements: Eberhard inequality, Peter Bierhorst proof, Vienna and NIST experiments

Other loopholes

- Finite statistics loophole
- “Measurability” loophole
- Time dependence (memory)
- Time trends, jumps, …

All fixed by Gill (2001, 2003) using martingale theory.
This also takes care of opportunistic stopping; it delivers *safe statistics*

Other loopholes (continued)

- Bell's fifth position - QM itself prevents implementation of a successful loophole-free experiment

- This would be a kind of "undecidability", built into the fabric of quantum mechanics itself (conspiracy?)

- Experimentally disproved by 2015 loophole-free experiments … if you trust them

Challenge

- Come up with a new loophole
- Give it a fancy name
- Show how to fix it
- There are some attempts to catalogue all known and perhaps as yet unknown loopholes

Metaphysical loopholes

- No amount of experimental precautions can rule them out

- However, one can try to make them *ridiculous*

Metaphysical loopholes

- The conspiracy loophole (predetermination)
    - Determinism / predetermination applies to the settings together with well as all the rest. You can't separate off different components of a composite physical system as if they were somehow "independent" of one another
    - Physical independence and statistical independence - see results from algorithmic complexity theory of Jonas Peters et al. in their book on Causality and Learning
        - Does the famous experiment with photons from distant galaxies solve this problem?
- Solipsism (ultimately, it's all in the mind anyway, stupid)
    - qBism, quantum Buddhism
- Many worlds theory
- Collapse-free QM

Computer challenges

- Quantum Randi challenge (Sasha Vongehr)
- My 2001 challenge to Luigi Accardi
- My recent challenge to Joy Christian

- QM also makes a prediction about 10 000 Bell experiments each with N = 1 carried out on 10 000 distant galaxies… so “time” and “memory” are *not* really issues
- But Bell-deniers usually do exploit time dependence, time trends, time breaks
- Example: Joy Christian and his team of helpful programmers

Statistical Science
2014, Vol. 29, No. 4, 512–528
DOI: 10.1214/14-STS490

Statistics, Causality and Bell's Theorem

Richard D. Gill

THEOREM 1. *Given an $N \times 4$ spreadsheet of numbers ± 1 with columns A, A', B and B', suppose that, completely at random, just one of A and A' is observed and just one of B and B' are observed in every row. Then, for any $\eta \geq 0$,*

$$\begin{aligned} &\Pr(\langle AB\rangle_{\mathrm{obs}} + \langle AB'\rangle_{\mathrm{obs}} + \langle A'B\rangle_{\mathrm{obs}} \\ &\qquad - \langle A'B'\rangle_{\mathrm{obs}} \leq 2 + \eta) \\ &\quad \geq 1 - 8e^{-N(\eta/16)^2}. \end{aligned} \tag{3}$$

Challenge

to a Bell-denier who is happy not to exploit *memory* of past *settings*

**Bell-denier generates 16000 x 4 spreadsheet of numbers +/-1
("counterfactual outcomes")**

**Trusted third party generates 16000 pairs of fair coin tosses
("actual settings")**

Compute CHSH for actual chosen settings, actually thereby designated outcomes

Win/lose criterium: < > 2.4 (halfway between LR bound 2 and QM max 2.8…

Bell martingale challenge

Success (in one trial):= outcomes equal & settings not (2, 2); or outcomes unequal & settings (2, 2)
X := # Successes in N trials
Win/lose criterium: Success rate := X/N < > 0.8
LR: E(X/N) ≤ 0.75; **QM**: E(X/N) ≤ 1/2 + $\sqrt{2}$ / 4 ≈ 0.85, with equality attainable

```
> N <- 800
> pbinom(0.80*N, N, 0.75, lower.tail = FALSE)
[1] 0.0003587726
> pbinom(0.80*N, N, 0.85, lower.tail = TRUE)
[1] 8.248497e-05
```

Sharp

CHSH “spreadsheet” challenge, 16 000 experiments each with N = 1

LR: E(S) ≤ 2; **QM**: E(S) ≤ 2 $\sqrt{2}$ ≈ 2.828, with equality attainable
Criterion: S < > 2.4

```
> eta
[1] 0.4
> N <- 16000
> 8 * exp( -N * (eta/16)^2)
[1] 0.0003631994
```

Not sharp

Some references

- http://www.sciphysicsforums.com/spfbb1/viewforum.php?f=6
- https://groups.google.com/forum/#!forum/bell_quantum_foundations
- https://royalsocietypublishing.org/toc/rsta/376/2118

  Theme issue ‘Hilbert's sixth problem’ compiled and edited by Luigi Accardi, Pierre Degond and Alexander N. Gorban
- https://arxiv.org/abs/1903.10537

Bell Inequality Violation with Free Choice and Local Causality on the Invariant Set

T. N. Palmer

Bell's Theorem requires any theory which obeys the technical definitions of Free Choice and Local Causality to satisfy the Bell inequality. Invariant set theory is a finite theory of quantum physics which violates the Bell inequality exactly as does quantum theory: in it neither Free Choice nor Local Causality hold, consistent with Bell's Theorem. However, within the proposed theory, the mathematical expressions of both Free Choice and Local Causality involve states which, for number-theoretic reasons, cannot be ontic (cannot lie on the theory's fractal-like invariant set I_U in state space). Weaker versions of Free Choice and Local Causality are proposed involving only the theory's ontic states. Conventional hidden-variable theories satisfying only these weaker definitions still obey the Bell inequality. However, invariant set theory, which violates the Bell inequality, satisfies these weaker definitions. It is argued that the weaker definitions are consistent with the physical meaning behind free choice and local causality as defined in space-time, and hence that Free Choice and Local Causality are physically too strong. It is concluded that the experimental violation of the Bell inequality may have less to do with free choice or local causality per se, and more to do with the presence of a holistic but causal state-space geometry onto which quantum ontic states are constrained.

Conclusion

- https://ieeexplore.ieee.org/document/8836453

  Bell's Theorem Versus Local Realism in a Quaternionic Model of Physical Space

- https://www.ime.unicamp.br/~agacse2018/guests

  The 7th Conference on Applied Geometric Algebras in Computer Science and Engineering

- https://mat-web.upc.edu/people/sebastia.xambo/A18/Abbott-0727.pdf

  The Vector Algebra War

- https://royalsocietypublishing.org/doi/full/10.1098/rsos.180526

  Quantum correlations are weaved by the spinors of the Euclidean primitives

- https://www.researchgate.net/publication/256838918_The_Reasonable_Ineffectiveness_of_Mathematics_Point_of_View

  Mathematics is a product of the imagination that sometimes works on simplified models of reality. Platonism is a viral form of philosophical reductionism that breaks apart holistic concepts into imaginary dualisms. I argue that lifting the veil of mathematical Platonism will accelerate progress. In summation, Platonic ideals do not exist; however, *ad hoc* elegant simplifications do exist and are of utility provided we remain aware of their limitations.

What is the connection between these items?
Do you agree with the last statement?
Why would someone make such a statement?
Does it matter?