The relativity of colocality is the ghost of quantum non-locality

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Talk topics

- Quantum Spacetime
- Interpretation of Quantum Mechanics
- Ontology of Spacetime
- Spacetime Foundations
- Quantum Foundations

Talk Outline

1. **Quantum (Bell) Nonlocality** (QNL) [2 slides]
   - EPR / Spooky action at a distance / Entanglement etc.
2. **Relativity of Colocality** (RoC) (Special Relativity) [6 slides]
   - Lorentz boost and symmetry
   - The Rest Principle
3. **Parallels** between these phenomena [3 slides]
   - Main claim: due to a series remarkable parallels, *relativity of colocality* is a **classical remnant** of *quantum nonlocality*.
4. **Conclusion**
   - Many-spaces theory (New!) [1 slide]

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[1] Nicolas Brunner et al. “Bell nonlocality”. In: Rev. Mod. Phys. 86 (2 Apr. 2014), pp. 419–478. DOI: 10.1103/RevModPhys.86.419.

[2] J. C. Sharp. “Symmetry of the Lorentz boost: the relativity of colocality and Lorentz time contraction”. In: European Journal of Physics 37.5 (2016), p. 055606.

Quantum Nonlocality (EPR) – In Brief

- In a typical ***Bell*** *(or* ***EPR****) experiment*, two entangled particles become spatially separated and are subsequently each measured by one of two distant observers, Alice and Bob.
- **1935** (Einstein, EPR); 1960s (John Bell); 1972 (Freedman & Clauser – Expt. proof)
- Measurement choices: x, y outcomes: a, b. Past factors: λ
- For a **local theory** we expect: $p(ab|xy,\lambda) = p(a|x,\lambda)\ p(b|y,\lambda)$
- but this **does not hold** for Alice and Bob (probabilities do not factorize.)

Brunner: ``*Locality is the crucial assumption behind this equation. In relativistic terms, it is the requirement that events in one* ***region of space-time*** *should not influence events in* ***spacelike separated regions****. … (bold added)*

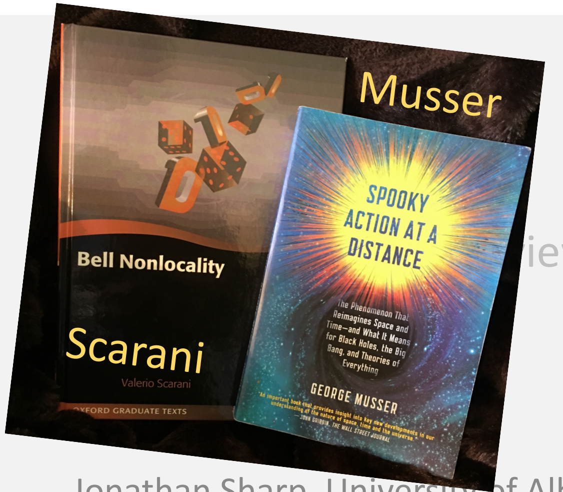
MY VIEW There are two distinct categories of distance in spacetime:
1) spatial and temporal **coordinate** distances (e.g.: **region of space-time**)
2) **invariant** spacetime intervals (e.g.: `**spacelike**')

… **BUT**: the **properties** of these two systems are often **implicit conflated** (e.g. Brunner above). This is a major problem.

Quantum Nonlocality (QNL) is a correlation between entangled particles which defies any classical explanation, does not violate causality.

$$p(ab|xy,\lambda) = \int_\Lambda d\lambda\ q(\lambda)\ p(a|x,\lambda)\ p(b|y,\lambda)$$

[10] Nicolas Brunner, Daniel Cavalcanti, Stefano Pironio, Valerio Scarani, and Stephanie Wehner. Bell nonlocality. *Rev. Mod. Phys.*, 86:419–478, Apr 2014. DOI: 10.1103/RevModPhys.86.419. URL https://link.aps.org/doi/10.1103/RevModPhys.86.419



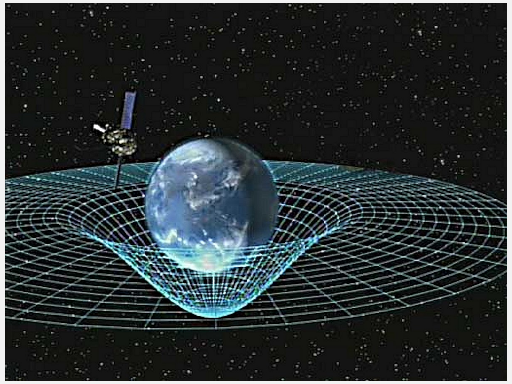
Catalogue of quantum nonlocality features

1. A spooky connection between parts (Einstein)
2. Correlation without causal influence (no signalling)
3. Correlation without predetermination (no local hidden variables)
4. Correlation with immunity to distance
5. An indeterminacy of spatial location (nonlocality)
6. A single inseparable non-local event (Shimony)
7. A form of distance that ignores/violates the spacetime metric.
8. A random element in the measurement process

THE PROBLEM
This is all well-confirmed experimentally (no Bell loopholes), and there is nothing paradoxical, … **except** major conflicts with **accepted notions of spacetime**.
We need to examine our vintage Minkowskian **spacetime ontology** with the same level of scrutiny matching that applied to the Bell experiments.
NEXT: Lets look at spacetime →

list is not definitive.

Consensus notion: spacetime as a 4D manifold



Special Relativity

[1] The Relativity of Colocality

The Lorentz Boost is **symmetric in *x* and *ct*.** For all Lorentz boost phenomena, there is time ←→ space symmetry:

Time	Space
Simultaneous: at the same time	**Colocal** : at the same spatial location
Relativity of Simultaneity	**Relativity of Colocality**

Relativity of Colocality (RoC): Inertial observers disagree on which events occur at the same spatial location. RoC = ``there is no absolute state of rest''. This is a very familiar phenomenon, but **under-appreciated.**

[2] The Rest Principle

The Rest Principle: each inertial observer is physically at rest. Each observer invariably attributes all motion in the world to other parties. I assert that in the ontology of spacetime that inertial observers really are at rest. Velocity is NOT arbitrary, a conventional choice, only relative, etc.

Next, take this seriously →

Lorentz boost (velocity transformation in SR)

$$\begin{pmatrix} ct_2 \\ x_2 \\ y_2 \\ z_2 \end{pmatrix} = \begin{pmatrix} \gamma & -\beta\gamma & 0 & 0 \\ -\beta\gamma & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} ct_1 \\ x_1 \\ y_1 \\ z_1 \end{pmatrix}$$

*J. C. Sharp. "Symmetry of the Lorentz boost: the **relativity of colocality** and Lorentz time contraction". In: European Journal of Physics 37.5 (2016), p. 055606.*

Note: the Relativity of Colocality is different from the *Relative Locality* proposed by *Amelino-Camelia, Freidel, Kowalski-Glikman, and Smolin PHYSICAL REVIEW D 84, 084010 (2011)*

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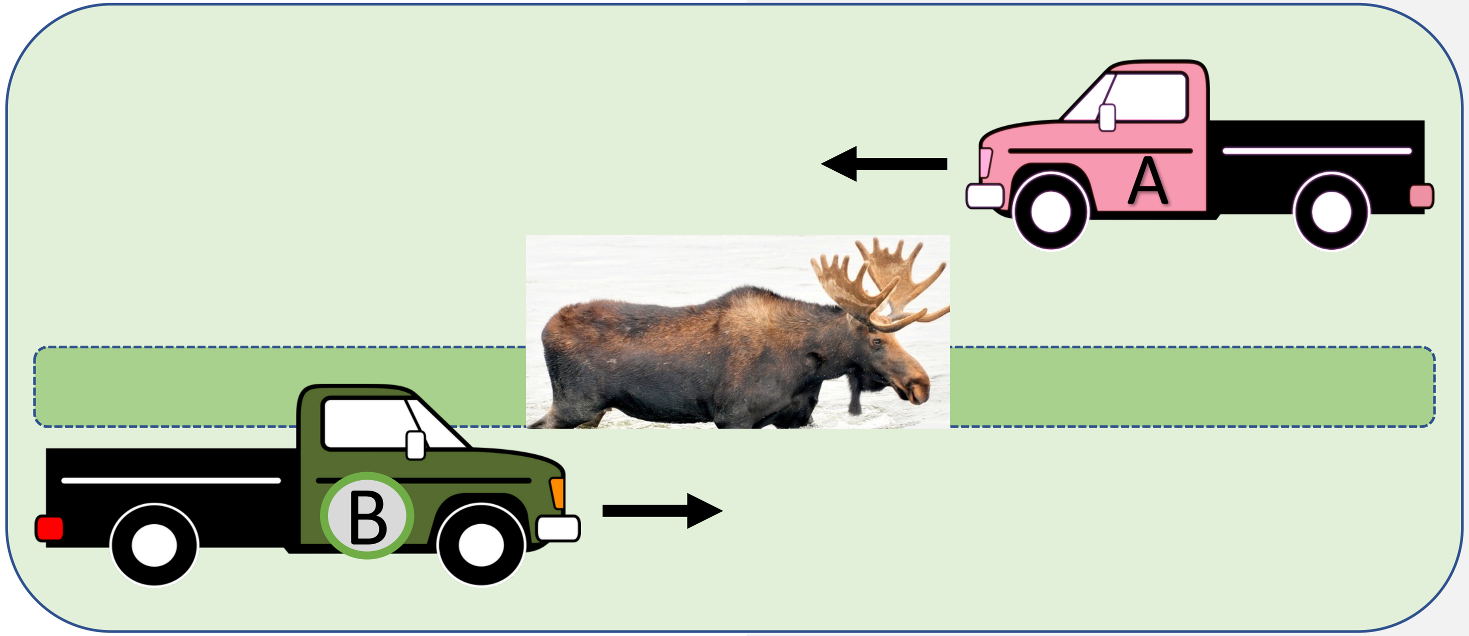
Moose and the Relativity of Colocality / Rest Principle

MOOSE - A moose is standing in the middle of a straight highway. Two pick-up trucks, travelling in opposite directions, approach.

COLLISION - There is a 3-way glancing **collision (event C)** between the trucks and the moose (M). Both vehicles, now damaged, **continue** on their original headings, but the moose is fatally injured.

The two drivers, (A) and (B), watch the animal falter in their rear view mirrors.

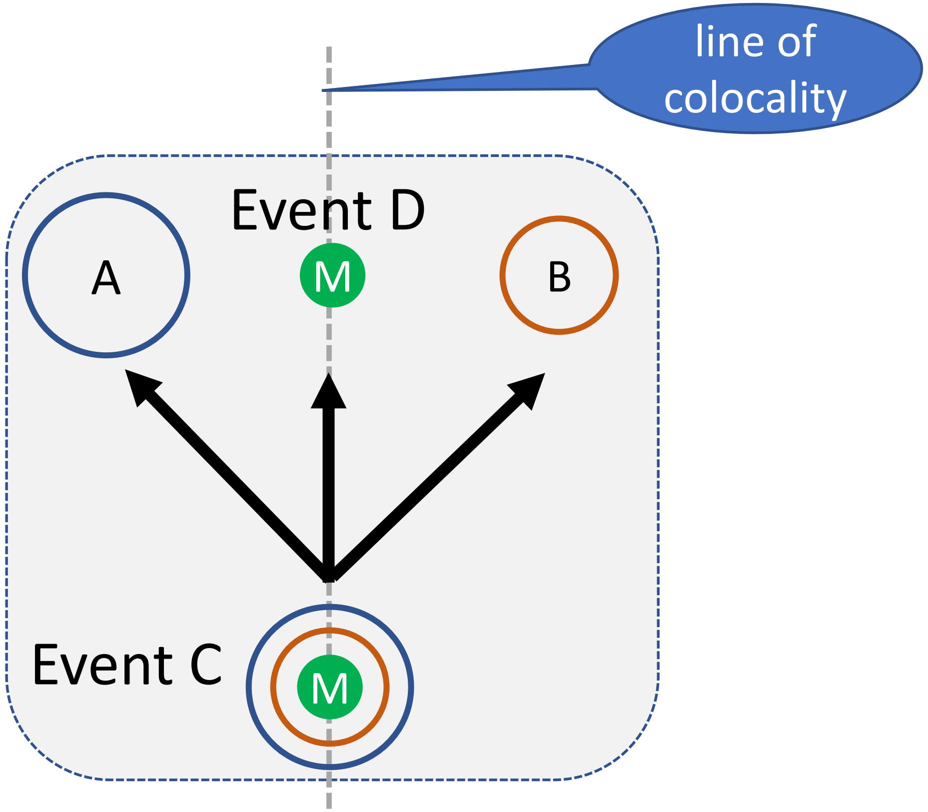


DEATH - From RoC and RP, each to itself is motionless, (A) observes the moose moving eastward from the collision site as it falters and dies, while for (B) it is moving westward.

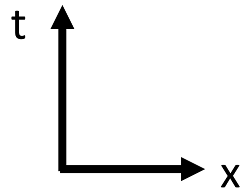
The moose disagrees with both, it finds itself dying motionless on the spot where it was struck (**event D**).

NEXT – We will consider the **ensemble of all observers**, i.e. A + B + M

Viewpoint of observer M



The whole ensemble is simultaneously, colocal at C. **This is the best possible attempt at coordinating everyone**



Consider an ensemble of (classical) inertial observers, initially all simultaneously colocated at reference event C.

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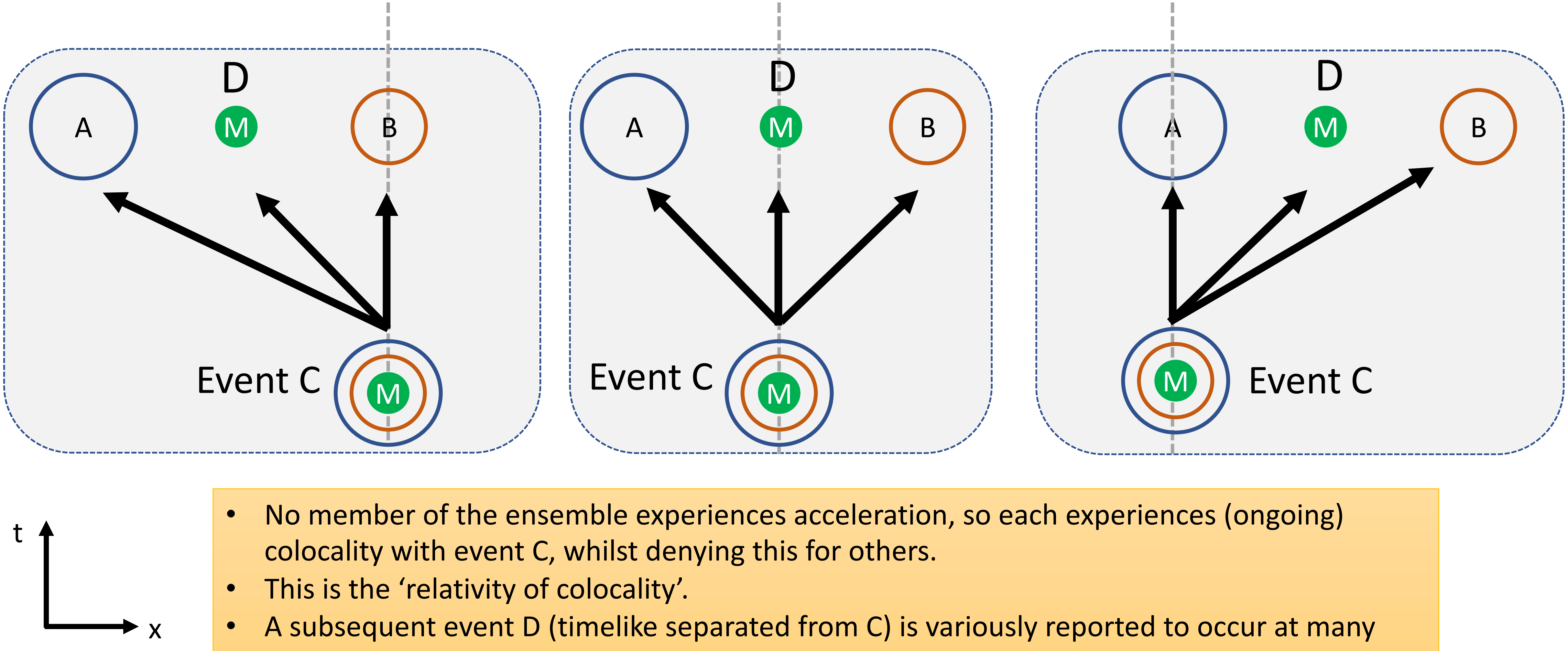
Three viewpoints; three observers

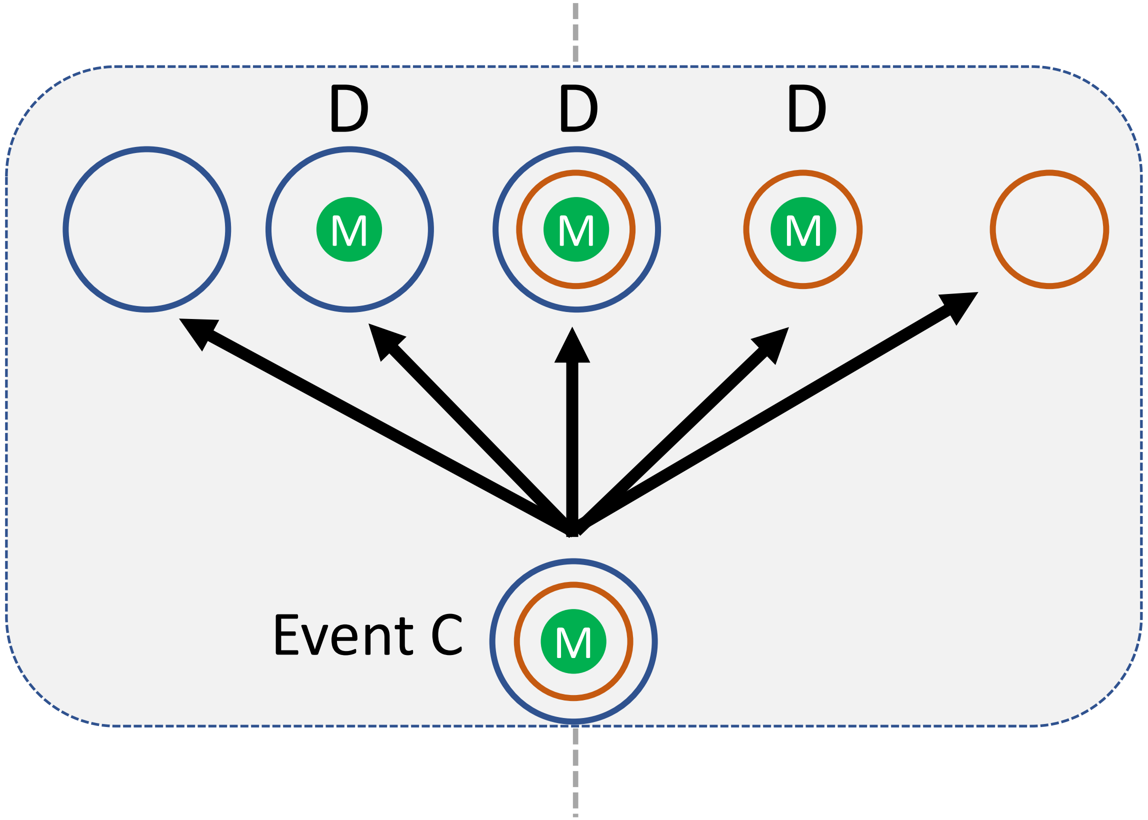


- No member of the ensemble experiences acceleration, so each experiences (ongoing) colocality with event C, whilst denying this for others.
- This is the 'relativity of colocality'.
- A subsequent event D (timelike separated from C) is variously reported to occur at many different spatial locations, relative to C.

Viewpoint for the **ensemble of all observers**

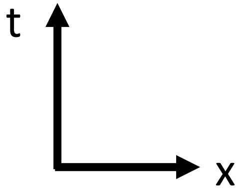
[2] All observers both are - and are not - colocal with C at time of D.

[1] Initially simultaneous & colocal: the best we can do.



[3] **For the ensemble** the location of the single event D is **indeterminate** (relative to C).

[4] This represents a species of **spatial correlation**, because event D correlates all the locations (relative to C) at which it occurs.



The constant refrain: ``... for the ensemble, relative to C''

Objections?

Objection 1: You might object that I have improperly conflated reference frames. You might say that I am only allowed to talk about each observer one by one.
Response: The physical system consists of an ensemble of many coexisting inertial observers. I should be allowed to describe the whole physical system. Also by treating all observers uniformly, I am following the **Principle of Relativity** to the letter.

Objection 2: You might say that we should anyway **ignore the observers** because they disagree with each other. You might say that reality consists of invariants such as the spacetime interval.
Response: This is a very common view. However ignoring observation is direct conflict with quantum theory, which is based on observables. We need compatible philosophies.

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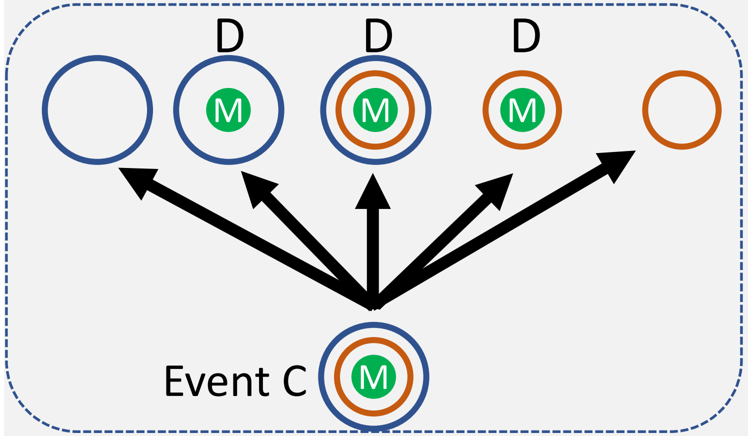

Only at the level of the **ensemble of all observers,** does this strange spatial correlation emerge.

The benefits of weirdness!

Our concern should be for the state of the ensemble as a whole, not for any single preferred observer.

3. The Ghost of Nonlocality

We have found `spatial correlation', which feels strangely like QNL.

Let's think about that. Consider two scenarios:

Entangled Quantum System	Moose + Trucks
An entangled pair of EPR particles (e.g. 2 photons)	An ensemble of classical inertial observers
Quantum Non-Locality	**Relativity of Colocality**
EPR of bipartite singlet state: particles A and B become entangled at C; subsequently detection(s) occur at events D_A *and* D_B.	*Moose thought experiment: members of the inertial ensemble (A,B,M) collide at event C; subsequent death(s) of M are reported at locations* D_A, D_B *and* D_M*, all relative to C.*

Seemingly quite different systems, yet there are remarkable parallels. →

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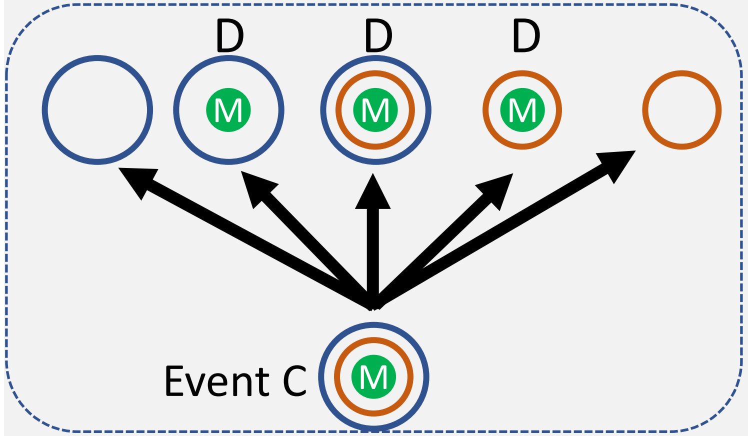
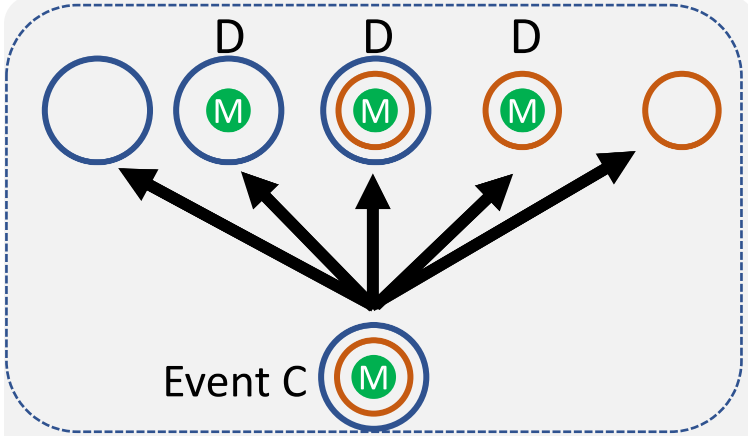


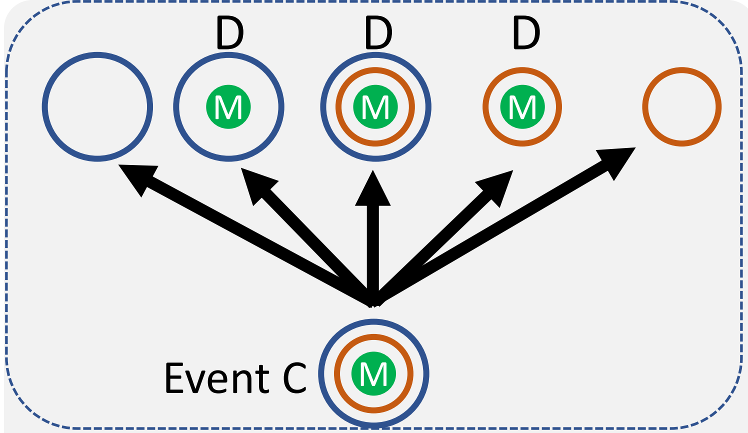
The key move is to analyze the **ensemble of all observers**, not isolated individuals.



Parallels

Phenomenon	**Quantum Non-Locality**	**Relativity of Colocality**
Scenario considered:	*EPR of bipartite singlet state: particles A and B become entangled at C; subsequently detection(s) occur at events D_A and D_B.*	*Moose thought experiment: members of the inertial ensemble (A,B,M) collide at event C; subsequent death(s) of M are reported at locations D_A, D_B and D_M, all relative to C.*
[2] **Correlation without causal influence**	Measurement outcomes at D_A and D_B are correlated, yet neither is a cause of the other.	Measurement outcomes at the events D are correlated (the moose always dies), yet no event is a cause of any of the others.
[5] An **indeterminacy** *of spatial location*	For the entangled quantum system, spatial location is indeterminate	For the ensemble, the spatial location of D relative to C is indeterminate, because colocality is relative.
Correlation that is immune to **distance**:	Yes	Yes

More Parallels



[6] Single inseparable **non-local event**	Measurement of entangled properties is a single inseparable event, but not localized	Death of the moose is a single inseparable event, yet observers report different locations, relative to collision C.
[8] **A random element** *in measurement process.*	The question: "Which particle is spin up?" cannot be answered deterministically. An 'answer' can only be generated by the probabilistic action of the Born rule (aka collapse of the wave function).	The question: *"Which member of the ensemble is* **really** *colocated with C?"* cannot be answered deterministically. An 'answer' could only be generated by a coin toss.

Conclusion– These parallels are strong.

Conclusions

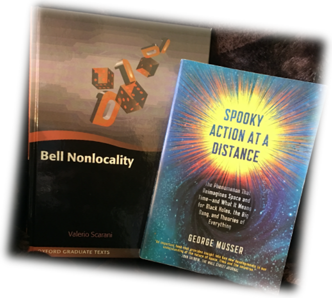
1. Starting point: symmetry of the Lorentz boost, …

2. Finding: **an ensemble of inertial observers is the classical limit of an entangled quantum system.**

3. A strong indication that quantum nonlocality is fully compatible with special relativity. Literature?

4. This leads to a new theory of **quantum spacetime.** See links for details (Many-spaces Theory).
   - ➢ Ensemble of inertial observers ←→ quantum momentum superposition

Questions?



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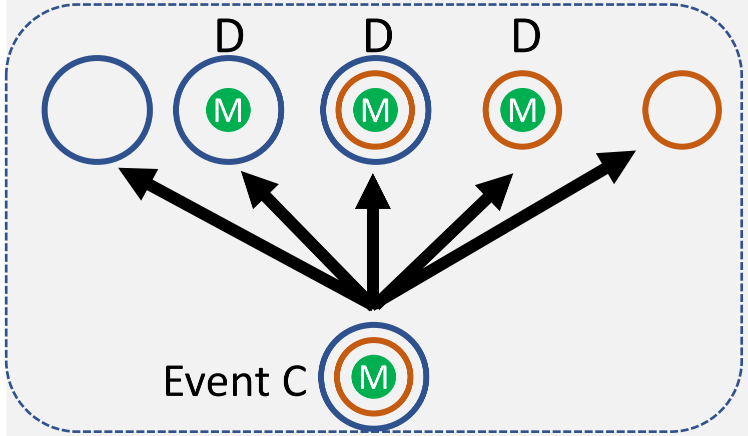

Sharp, J.C. One Universe, Many Spaces: A Non-Local, Relativistic Quantum Spacetime. Preprints 2018, 2018050003 (doi: 10.20944/preprints201805.0003.v1).

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