Title: Backward causation models for quantum correlations

Date: Jan 15, 2008 04:00 PM

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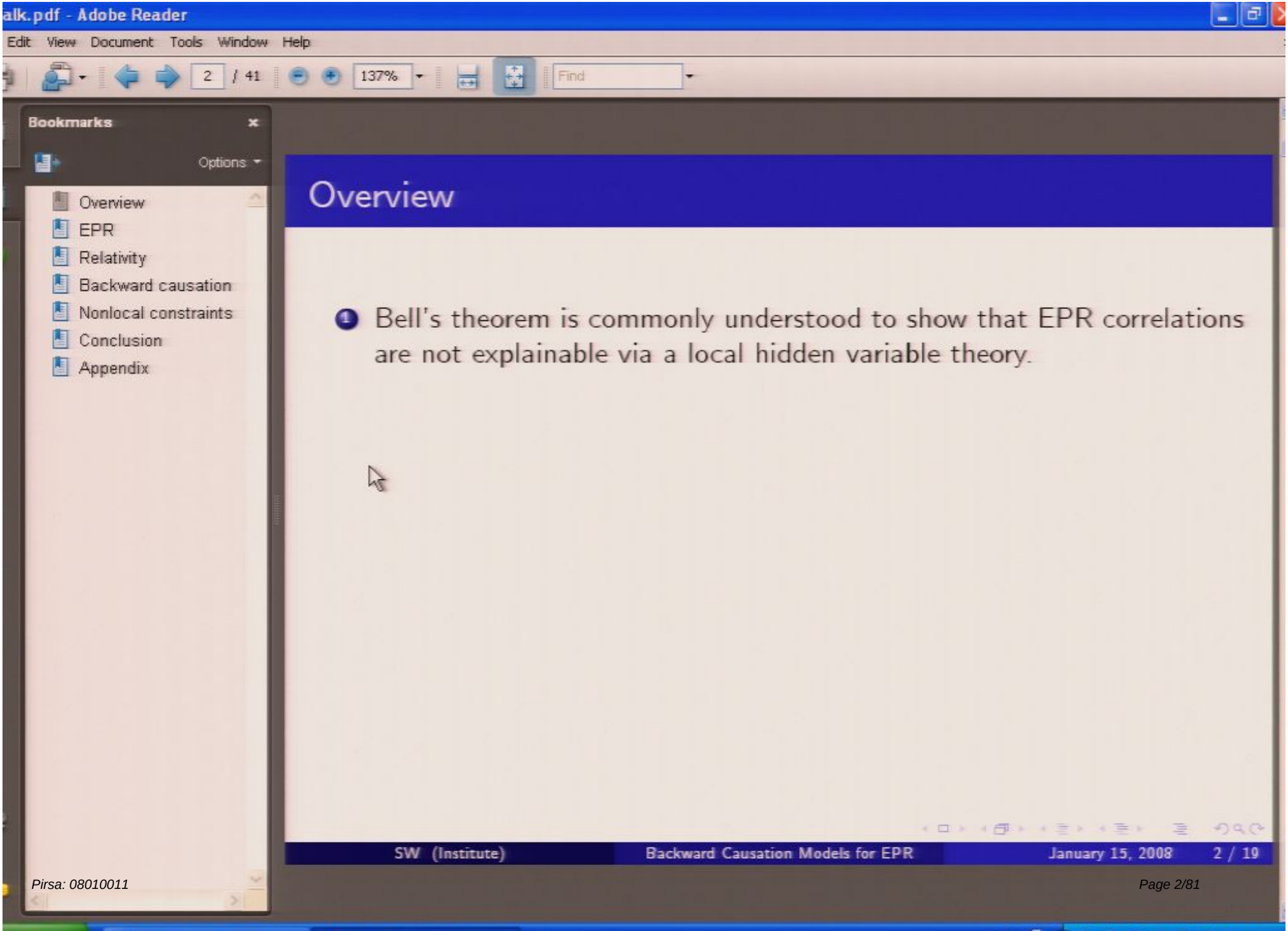
Abstract: Bell\\\'s theorem is commonly understood to show that EPR correlations are not explainable via a local hidden variable theory.
But Bell\\\'s theorem assumes that the initial state of the particles is independent of the final detector settings. It has been proposed that this independence assumption might be undermined by a relativistically-allowed form of \\\"backward causation\\\", thereby allowing construction of a local hidden-variable model after all. In this talk, I will show that there is no backward causation model which yields the desired correlations. However, there are other physical scenarios yielding nontrivial nonlocal correlations which violated Bell\\\'s independence assumption. I will present two.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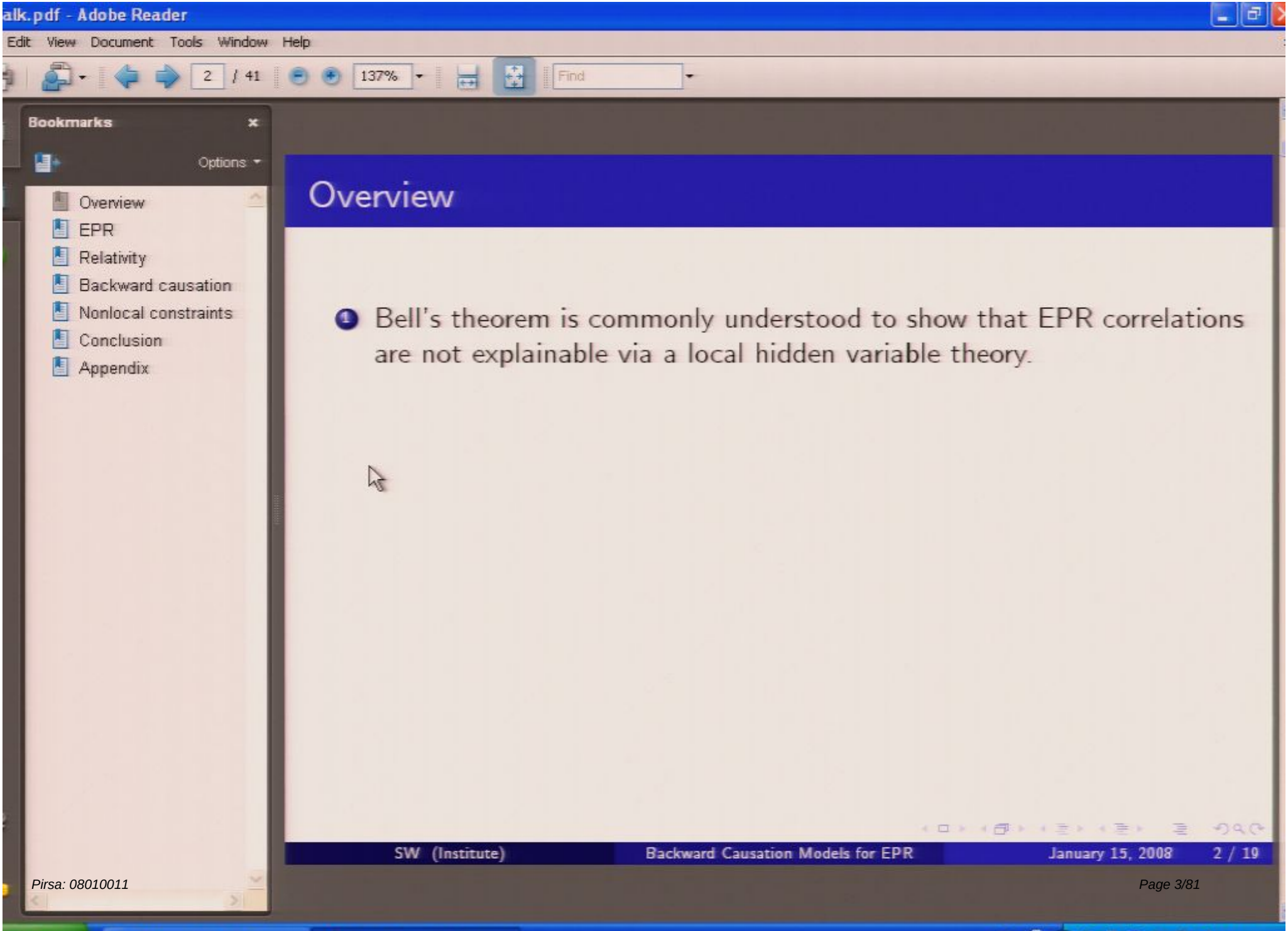
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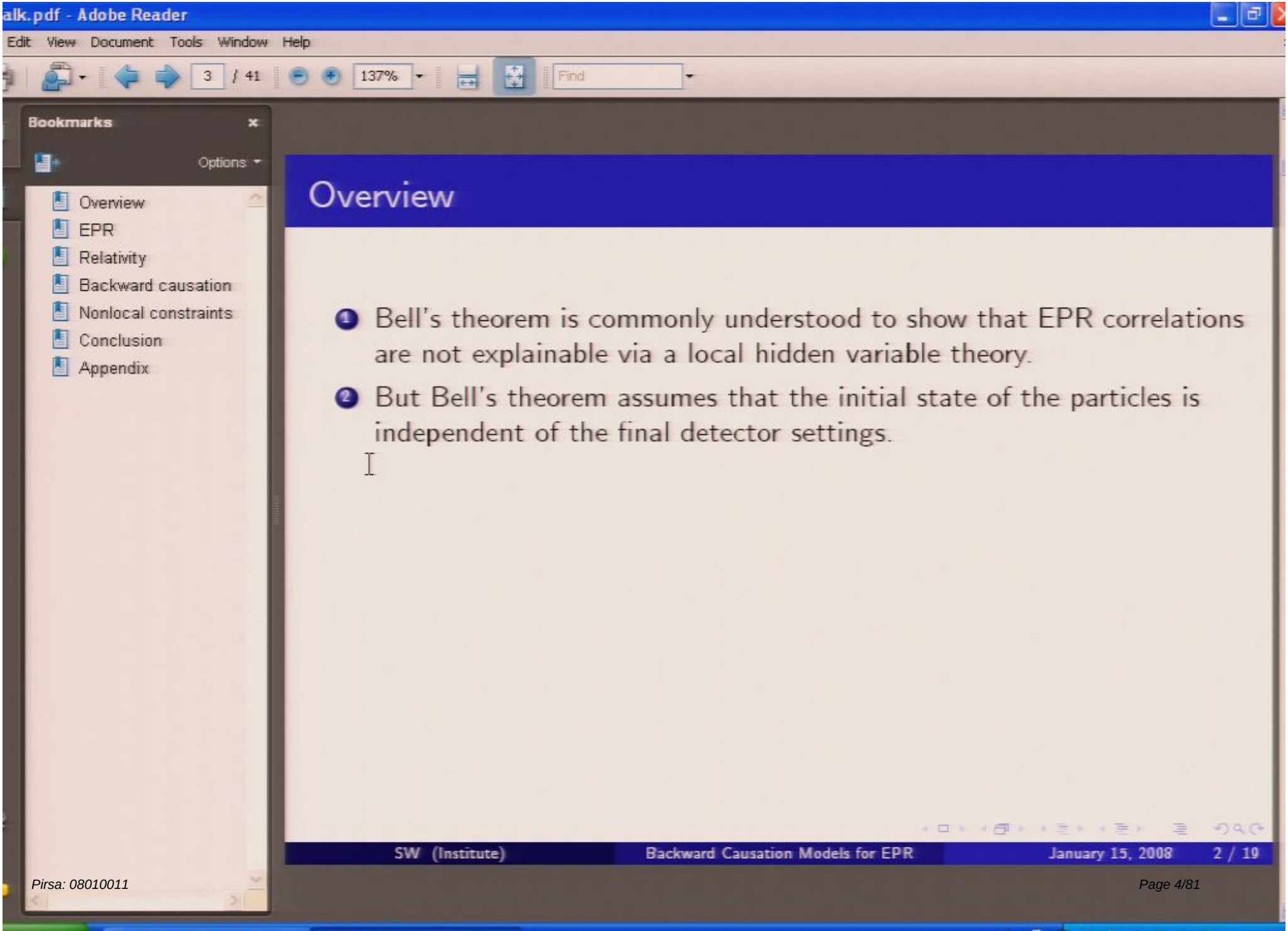
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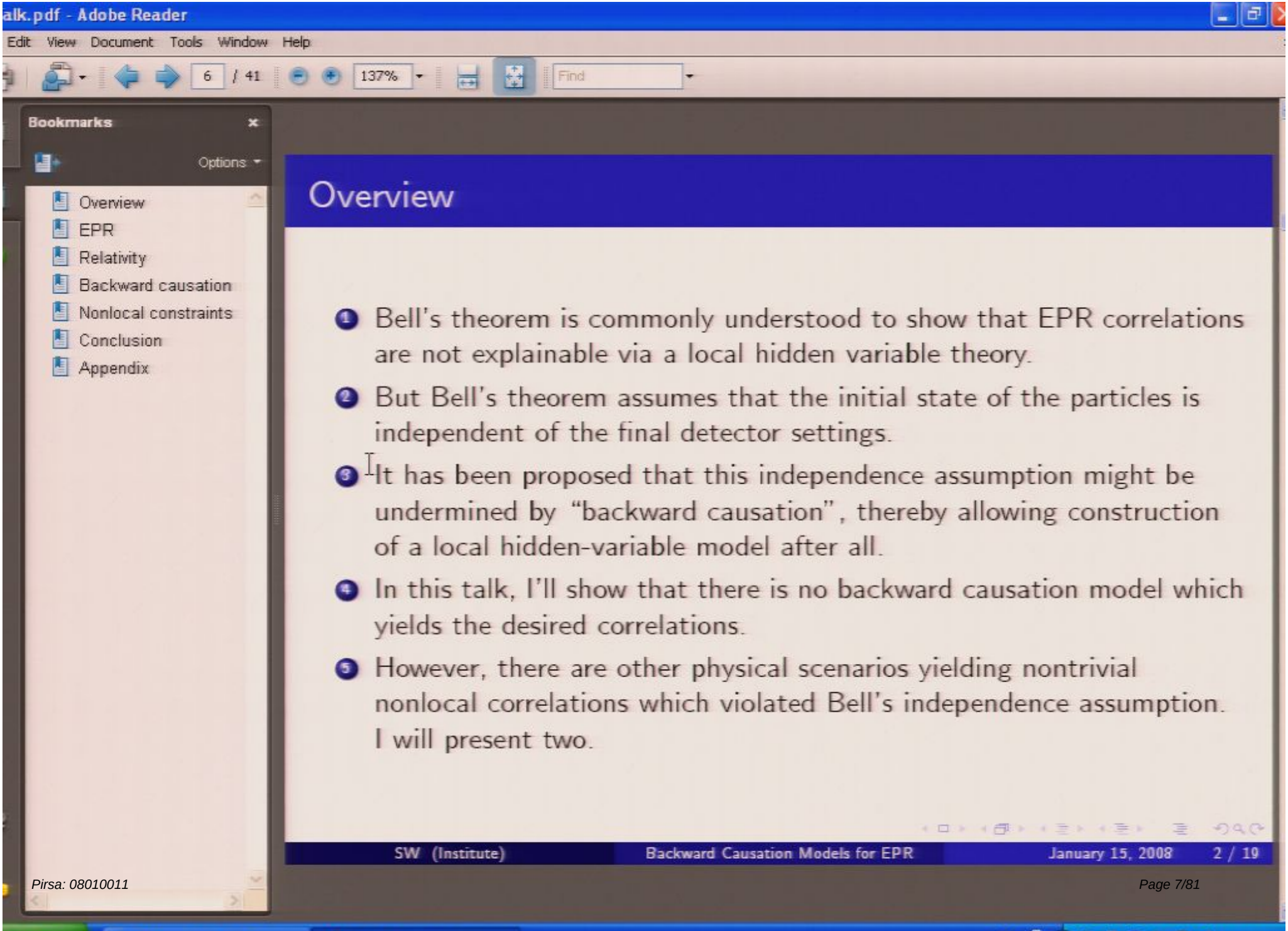
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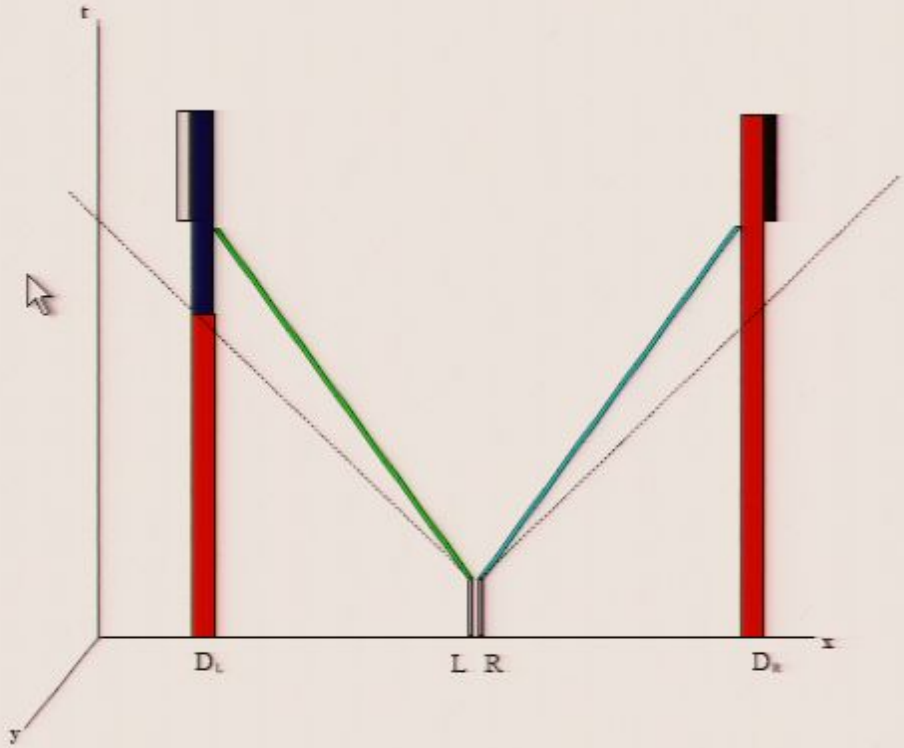
EPR



D_L and D_R are *detectors*, the color indicating their orientation. L and R are *particles*, the color indicating their properties, which in conjunction with the detector settings determine the *outcomes*, indicated by the gray and black boxes.

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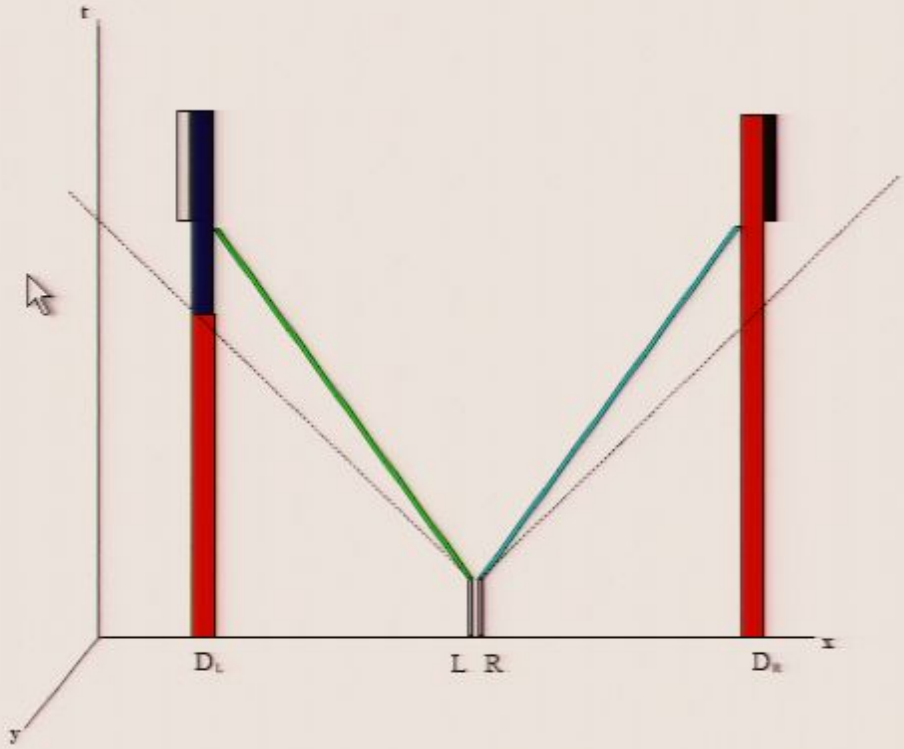

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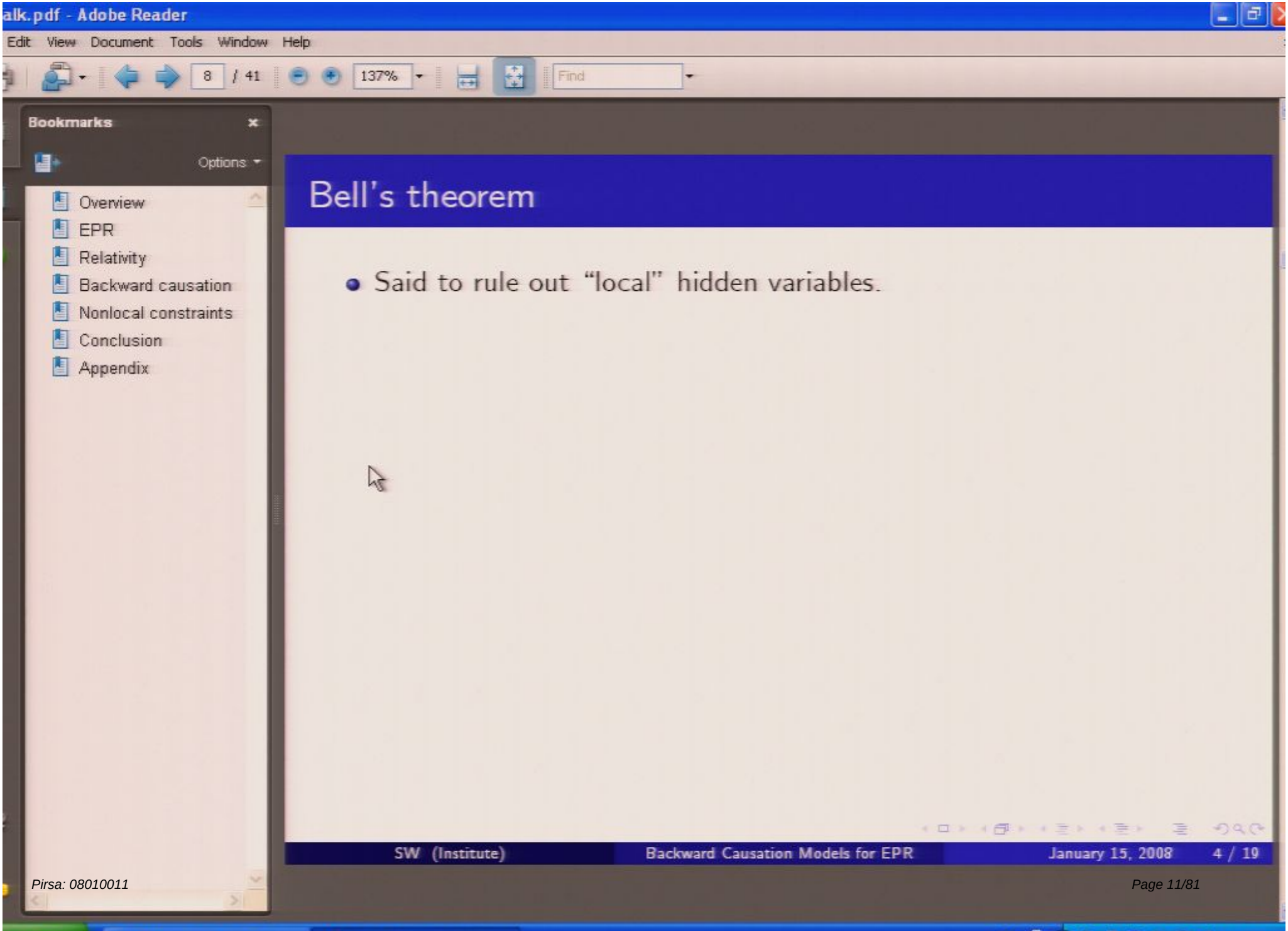
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Bell's theorem
• Said to rule out "local" hidden variables.
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Bell's theorem

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- Involves the assumption that the state $\lambda = \langle L(0), R(0) \rangle$ of the particles is uncorrelated with the detector settings, in that it assumes that
$$E(a,b) - E(a,b') = \int \rho(\lambda)\{A(a,\lambda)B(b,\lambda) - A(a,\lambda)B(b',\lambda)\}d\lambda,$$
where a and a' are possible orientations of detector D_L, b and b' are possible orientations of detector D_R, and $A(a,\lambda)$ and $B(b,\lambda)$ are the expectation values for measurements of a and b, respectively, in state λ.

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where a and a' are possible orientations of detector D_L, b and b' are possible orientations of detector D_R, and $A(a,\lambda)$ and $B(b,\lambda)$ are the expectation values for measurements of a and b, respectively, in state λ.
- If $\rho(\lambda) = f(D_L, D_R)$, then e.g. $\rho_{ab}(\lambda)$ need not be equal to $\rho_{ab'}(\lambda)$, so
$$E(a,b) - E(a,b') = \int \{\rho_{ab}(\lambda)A(a,\lambda)B(b,\lambda) - \rho_{ab'}(\lambda)A(a,\lambda)B(b',\lambda)$$

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- It has periodically been argued (Costa de Beauregard; Cramer; Price) that relativity does not require this, since the detectors are causally connectible (lightlike or timelike) to the emission of the particles.

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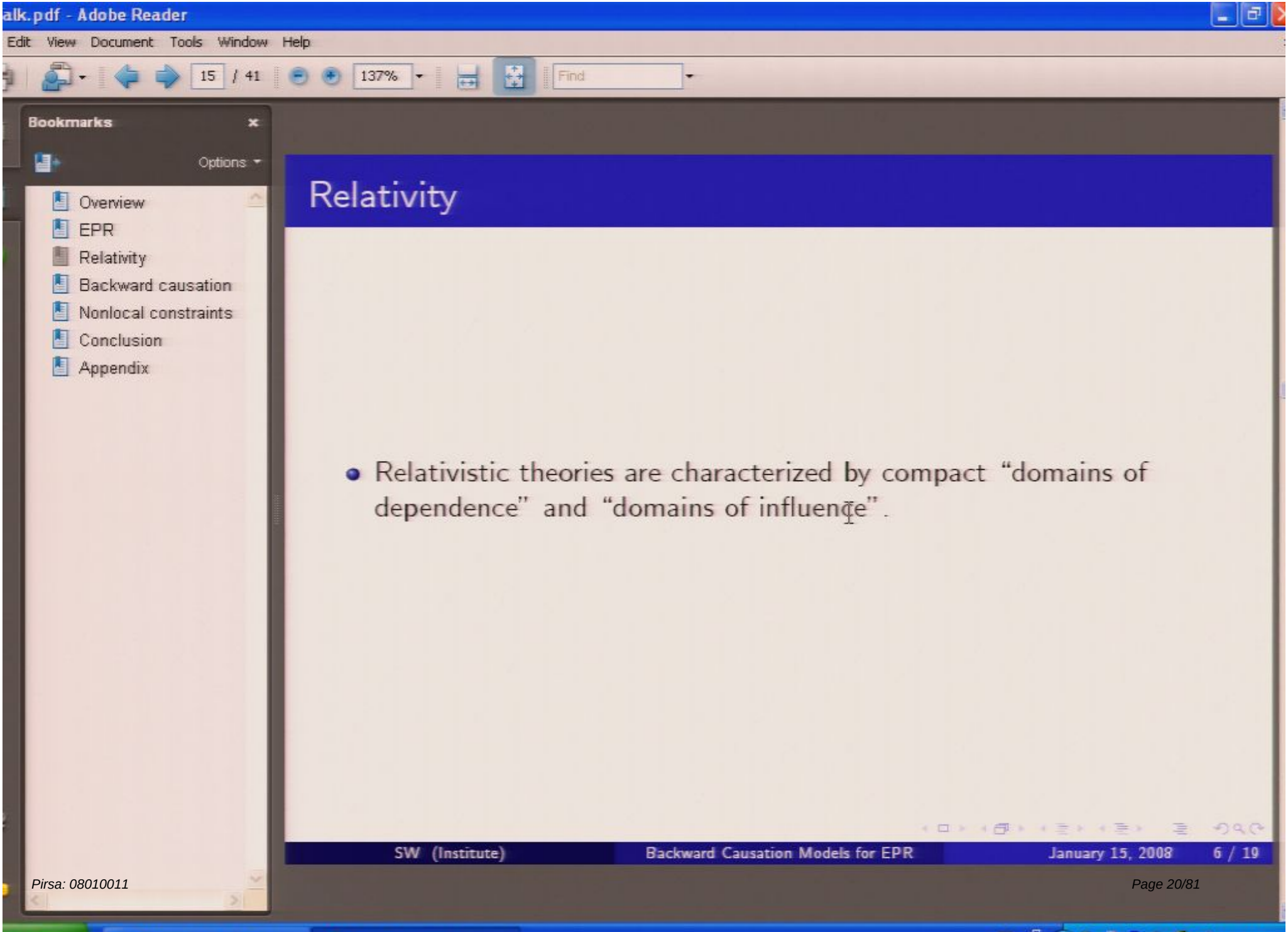
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Relativity
• Relativistic theories are characterized by compact "domains of dependence" and "domains of influence".
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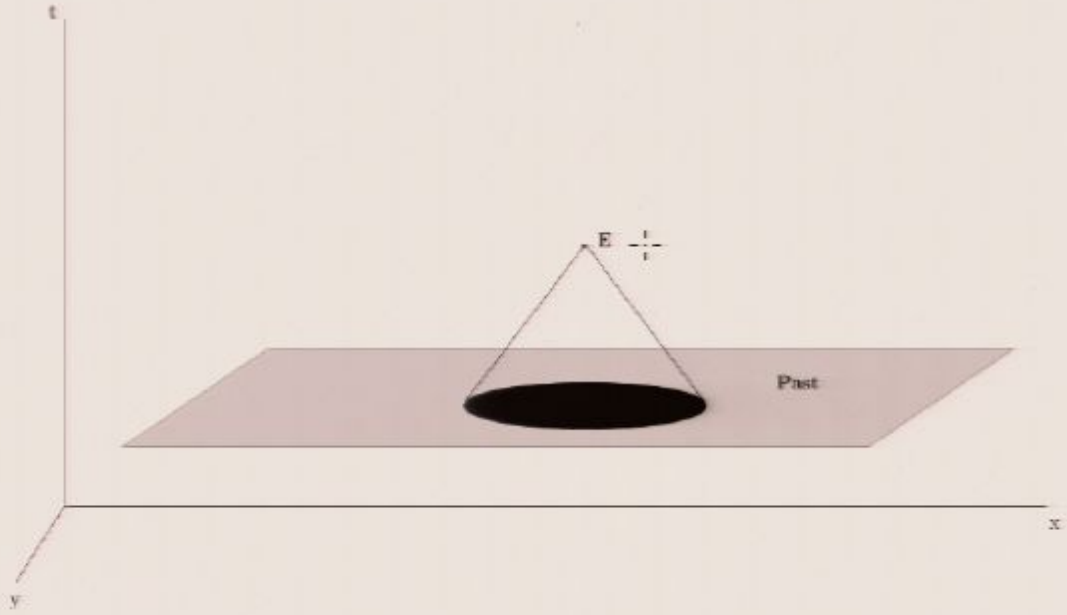
Relativity

- Domain of dependence:



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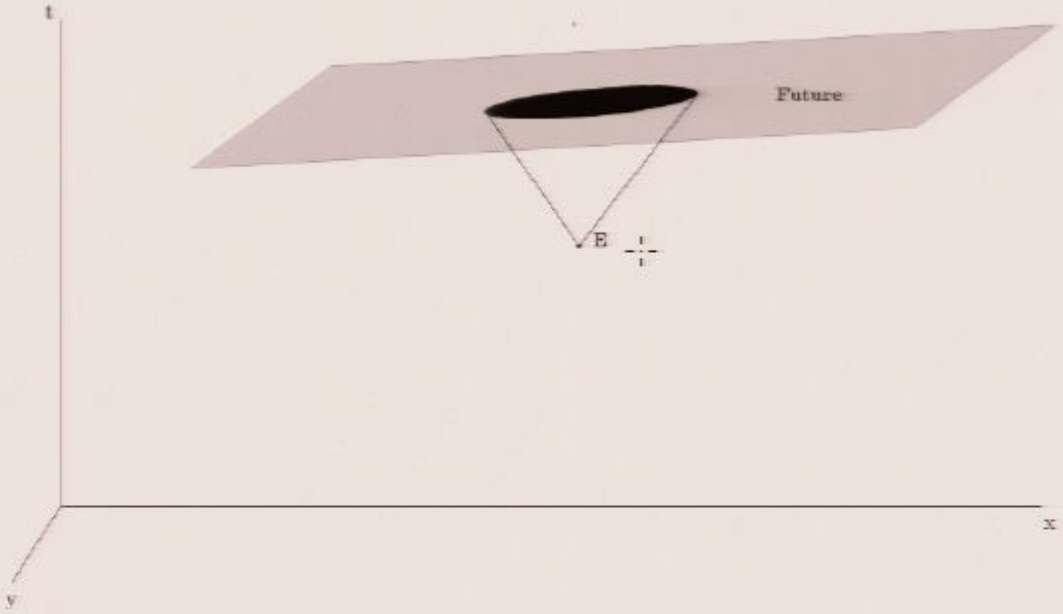
Relativity

- Domain of influence



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Relativity

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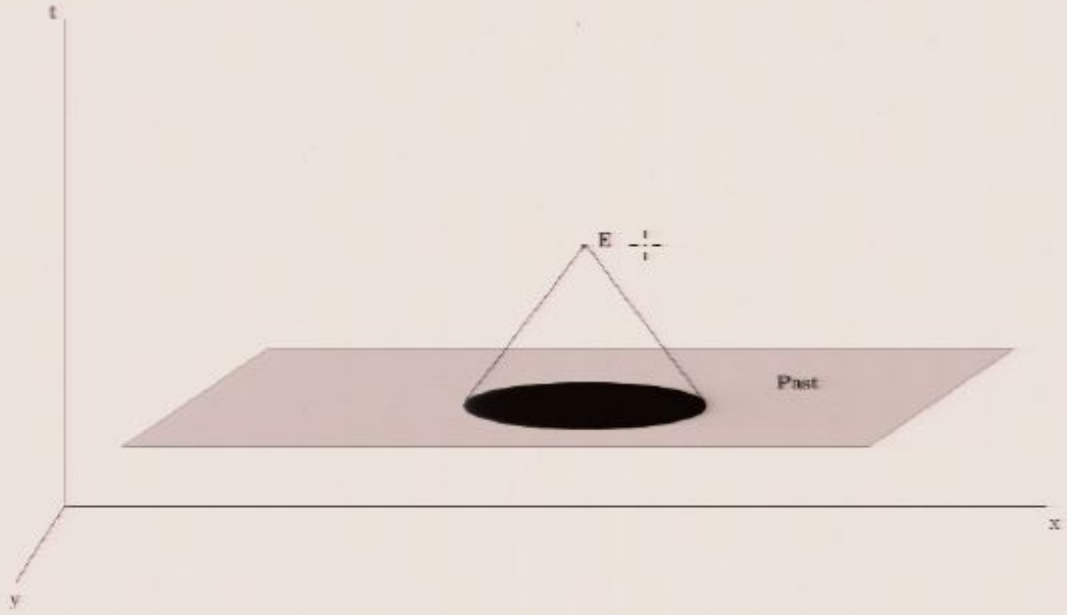
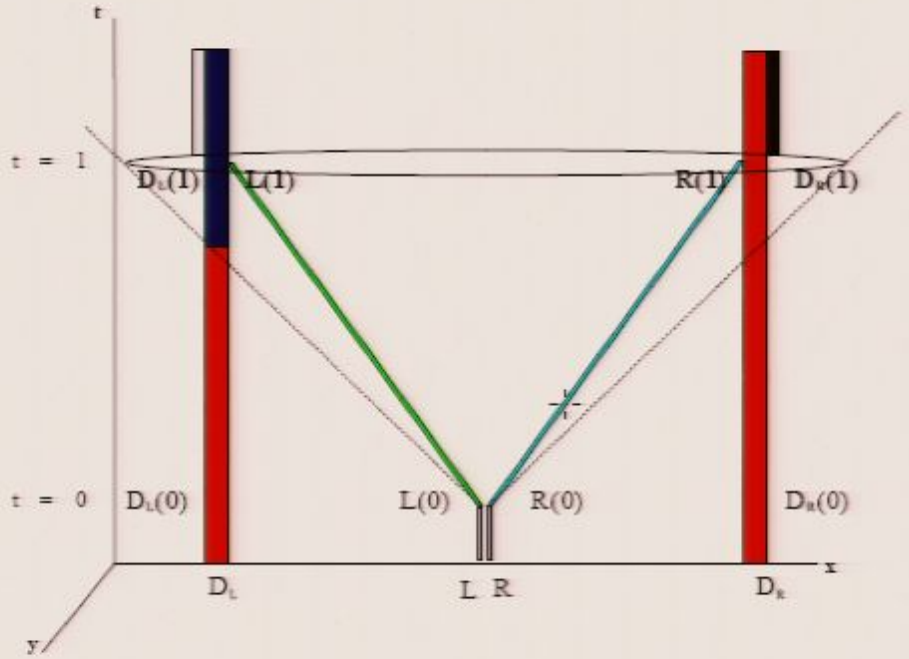


Backward causation I



- The idea is that the initial state $\lambda = \langle L(0), R(0) \rangle$ is correlated with the final detector setting, as a consequence of a "causal influence" from the future.

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Relativity

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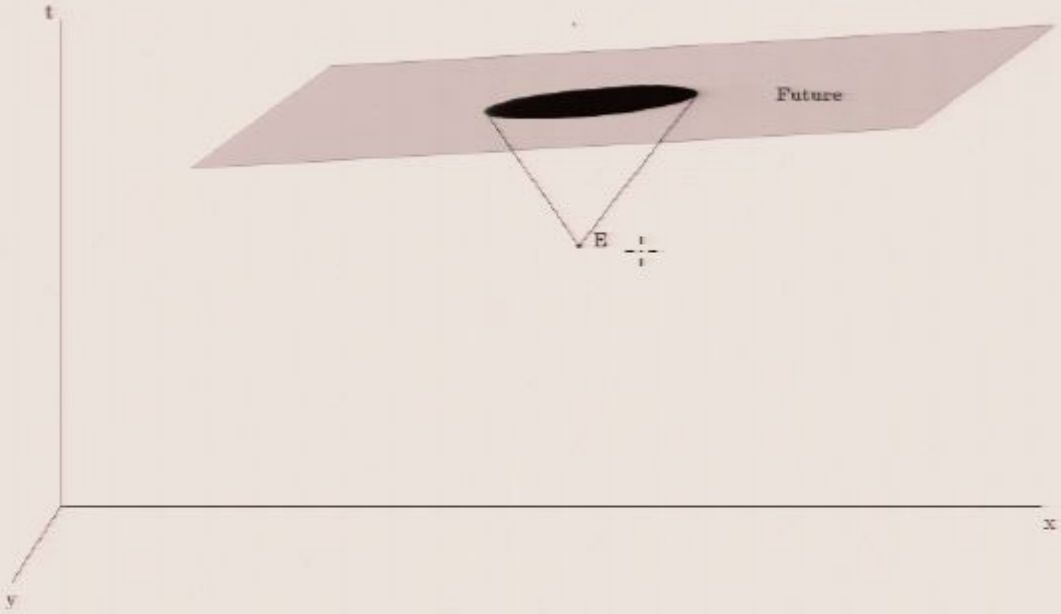

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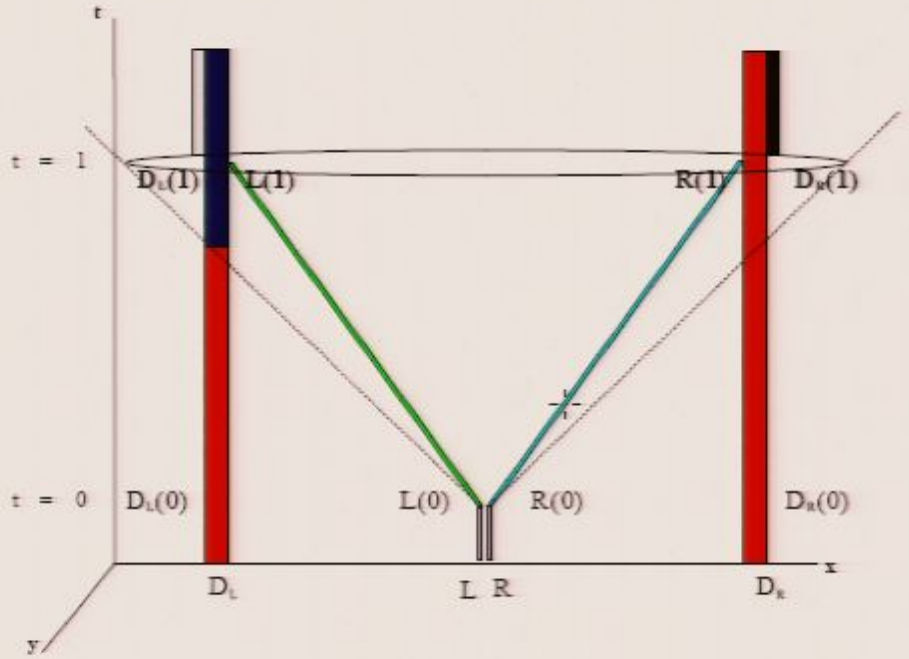

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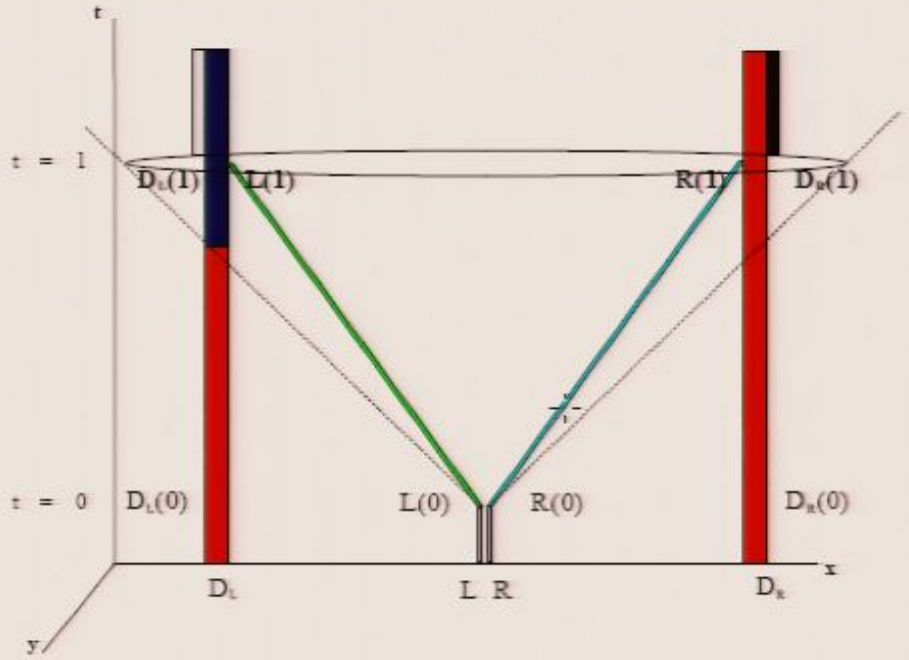

- The detectors may have different settings at different points in the forward lightcone. We will ignore this and grant that somehow the relevant setting is the one at the time of detection ($t = 1$ above).

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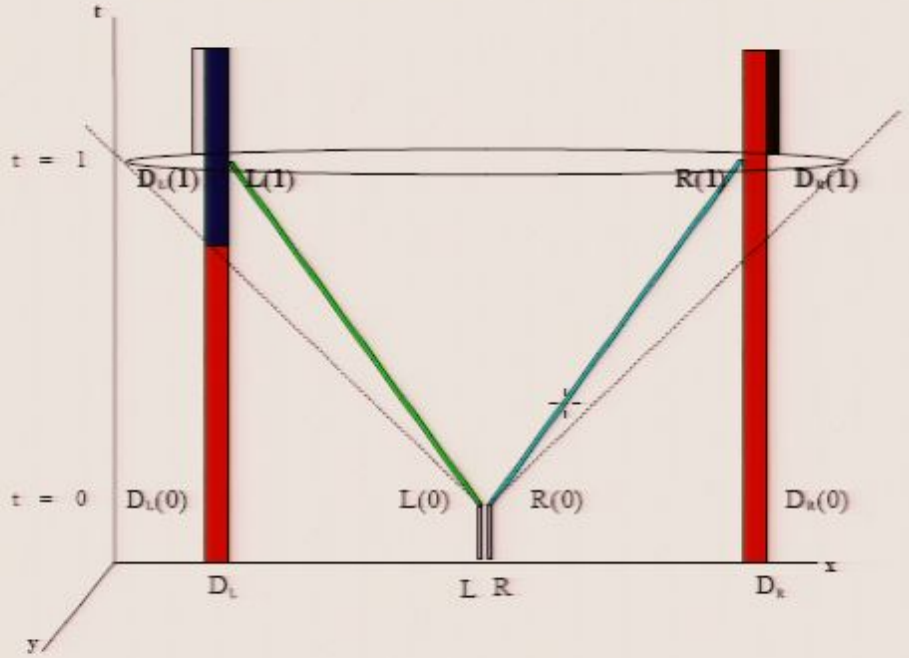

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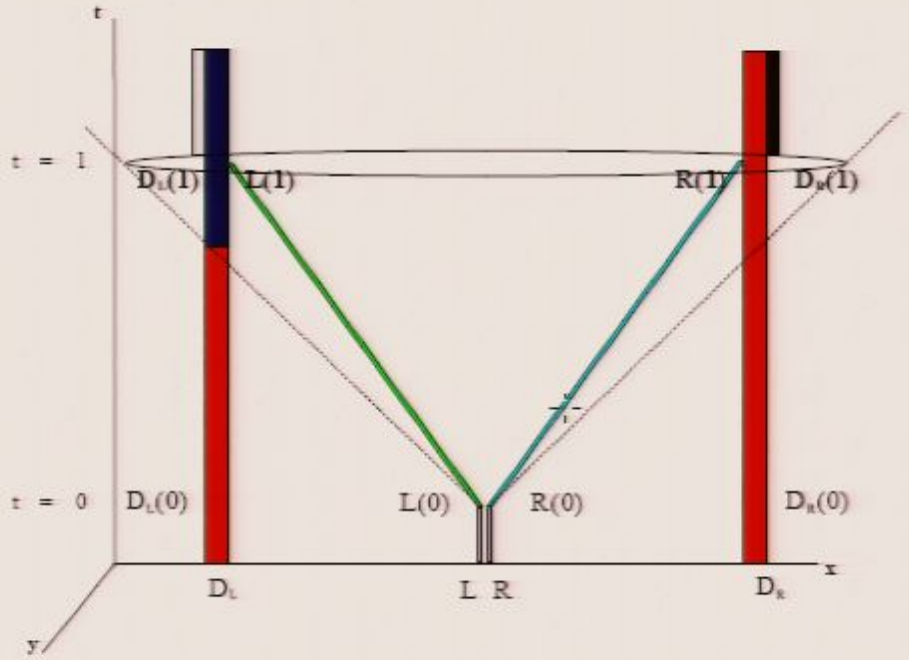

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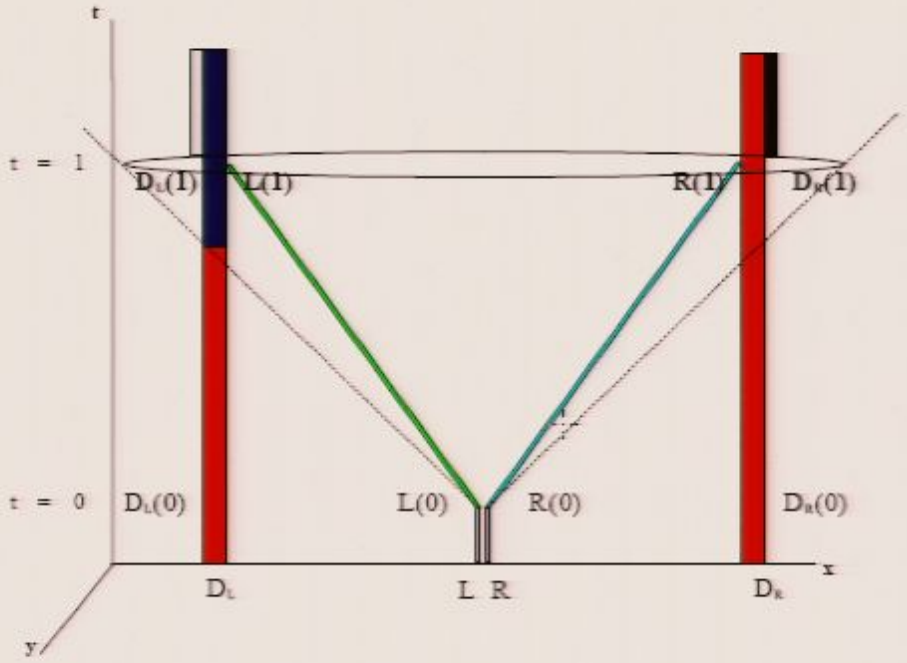

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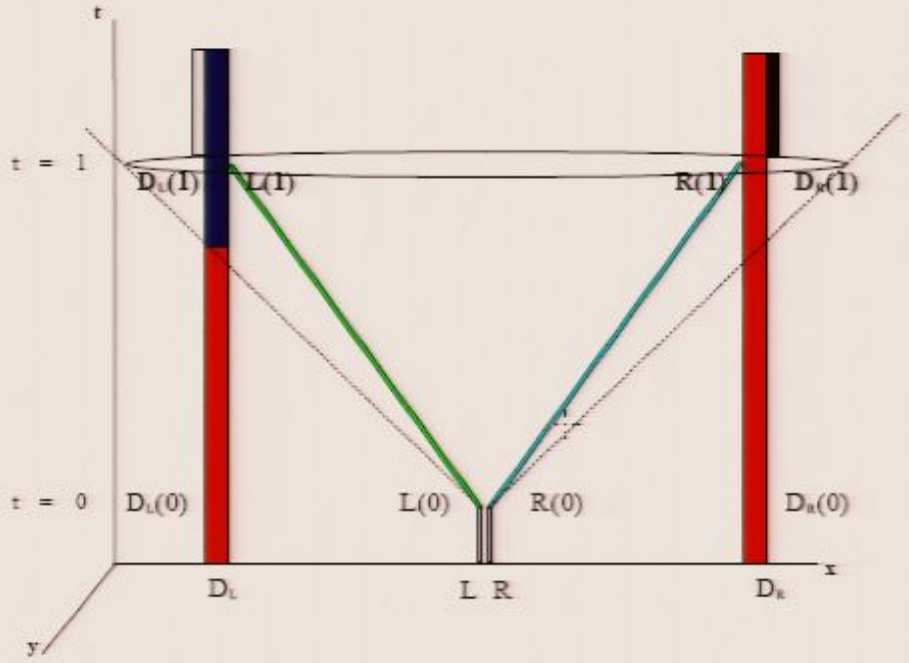

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- This is a kind of backward causation, but not one which will do the job.

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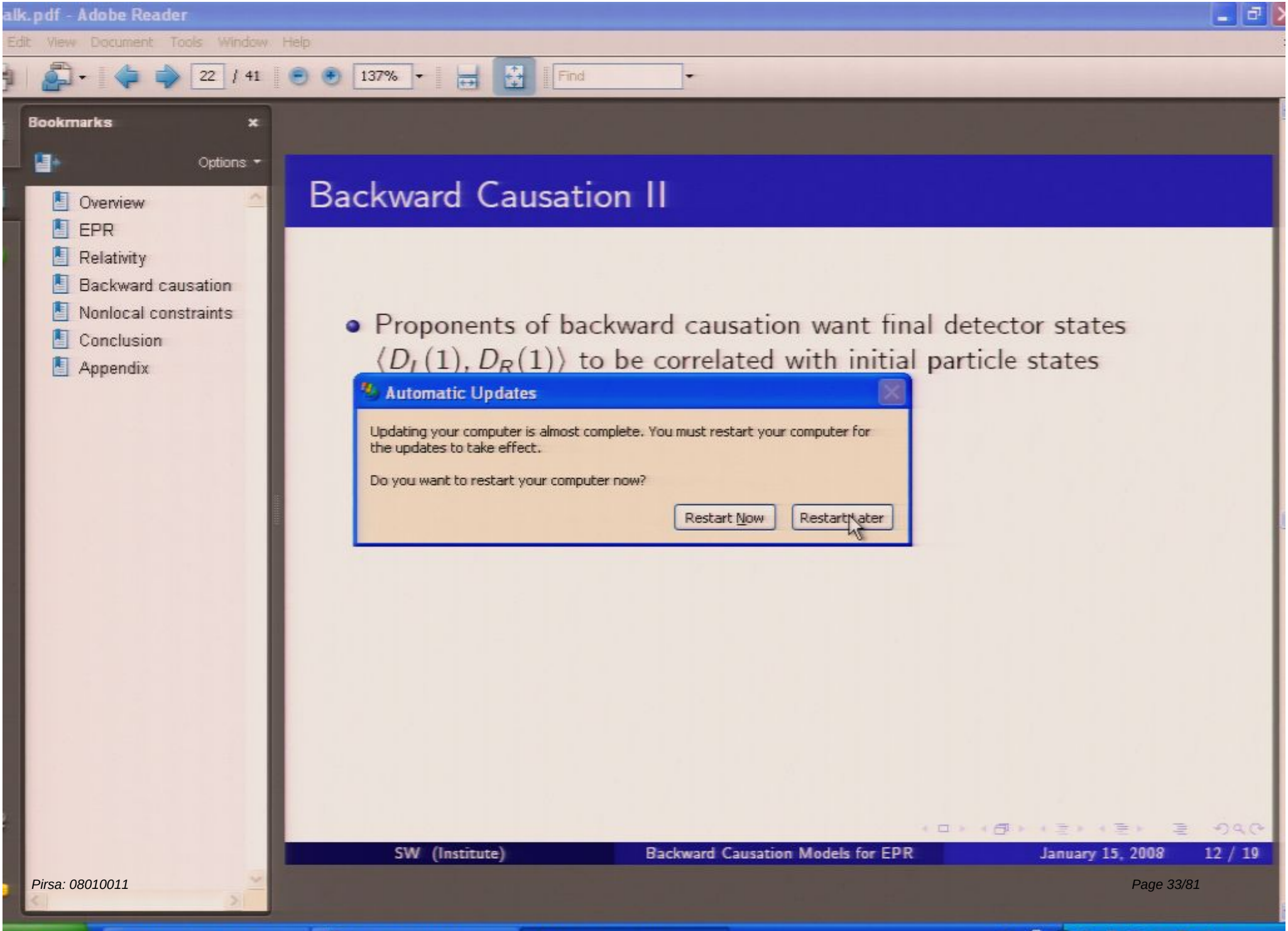
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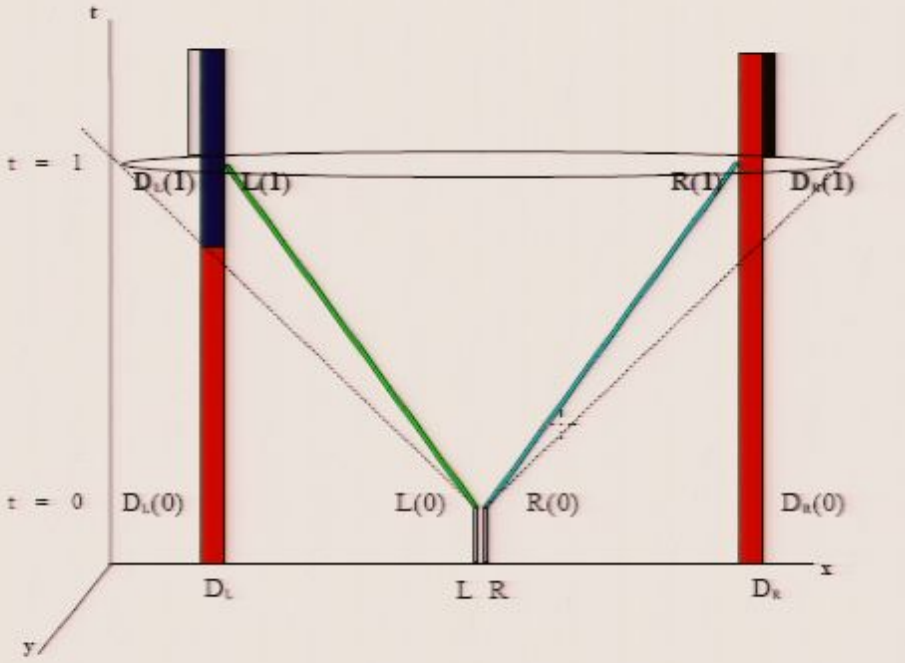

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  - The final detector states are correlated with the final particle states, and consequently with the initial particle states. Different final detector settings are inevitably correlated with different final particle states. There is no *causation* here, however.

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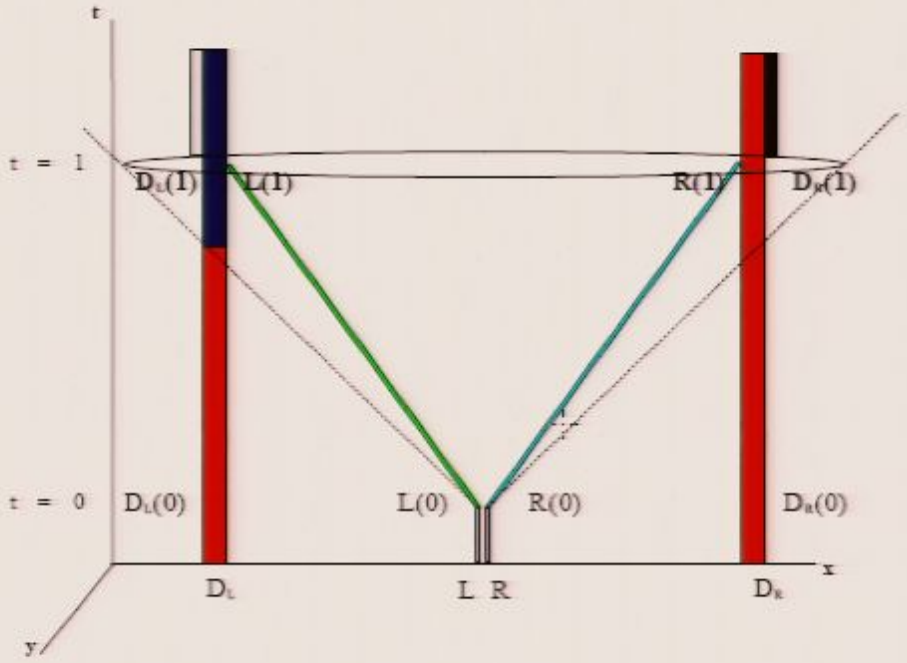

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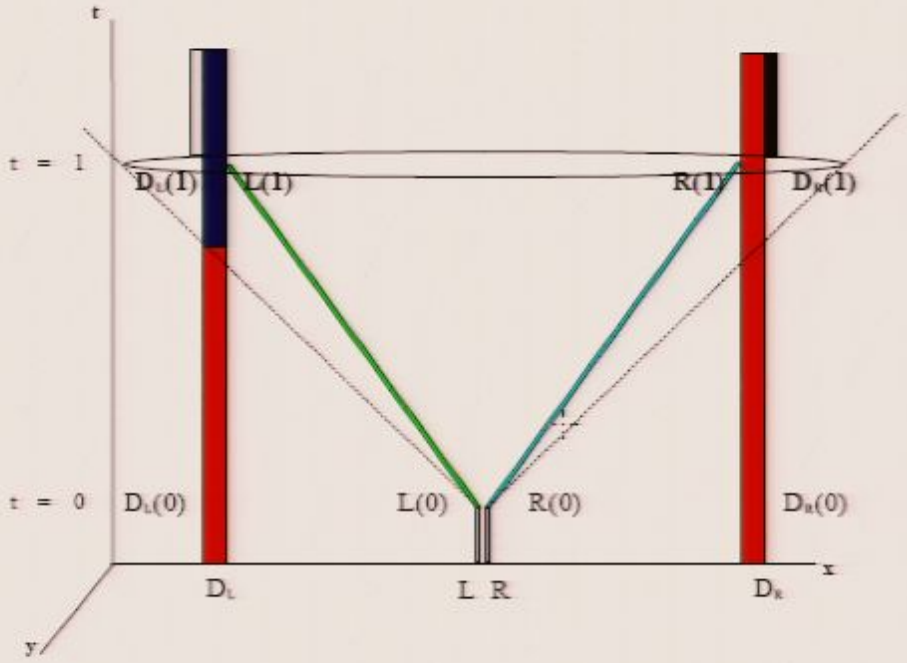

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- Reply: This suggests a correlation between $D_L(1)$ and $L(1)/L(0)$, and $D_R(1)$ and $R(1)/R(0)$, violating the independence assumption, albeit in a seemingly plausible way.. However, in order to reproduce the observed quantum statistics, one needs correlations between $L(1)$ and $R(1)$ as well.

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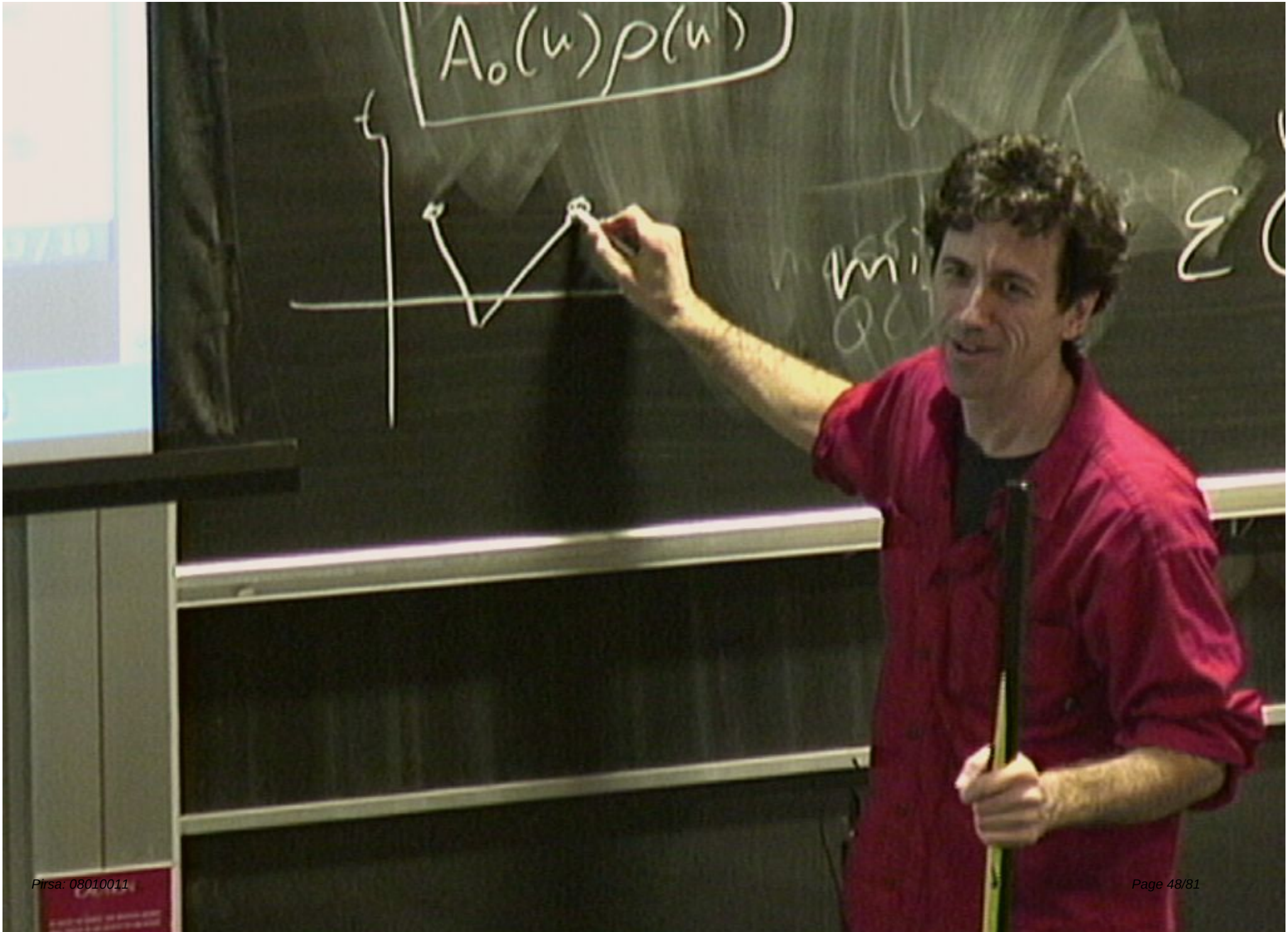
- Thus a hidden-variable theory which is to account for the perfect (anti)correlations when both detectors have the same setting will be one in which $D_L(1)$ is correlated with *both* $L(1)$ and $R(1)$. Since $D_R(1)$ is similarly correlated (by hypothesis), our theory will be such that the independence condition is violated.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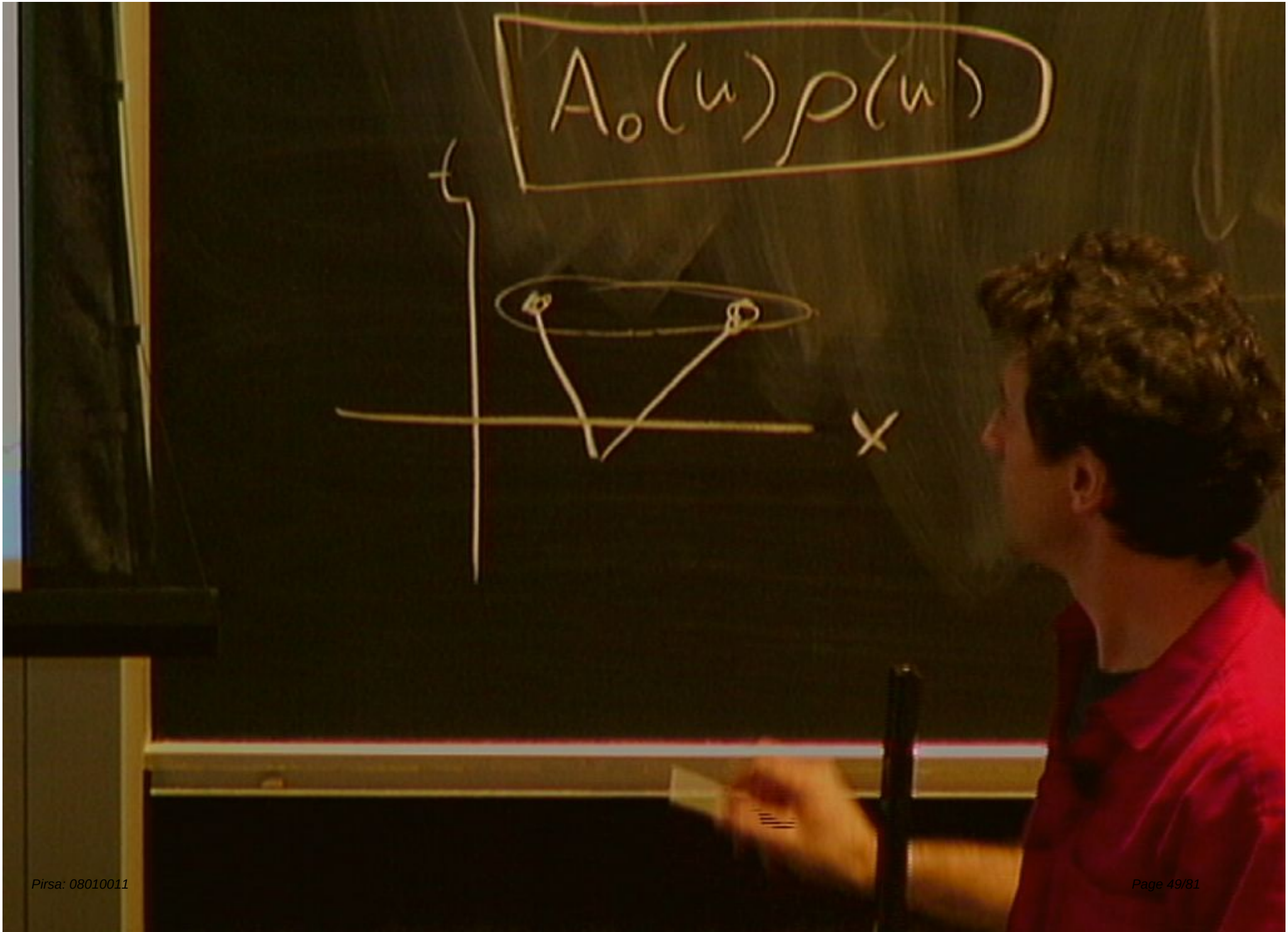
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Backward Causation III

- Proposals that "backward causation" might give a local explanation for EPR correlations therefore amount to proposals that there are correlations amongst the data at any given time which are *non*-causal in nature.
- Objection: What about the possibility that the detectors emit particles "into the past", the particle properties thereby depending on their orientation?
- Reply: This suggests a correlation between $D_L(1)$ and $L(1)/L(0)$, and $D_R(1)$ and $R(1)/R(0)$, violating the independence assumption, albeit in a seemingly plausible way.. However, in order to reproduce the observed quantum statistics, one needs correlations between $L(1)$ and $R(1)$ as well.
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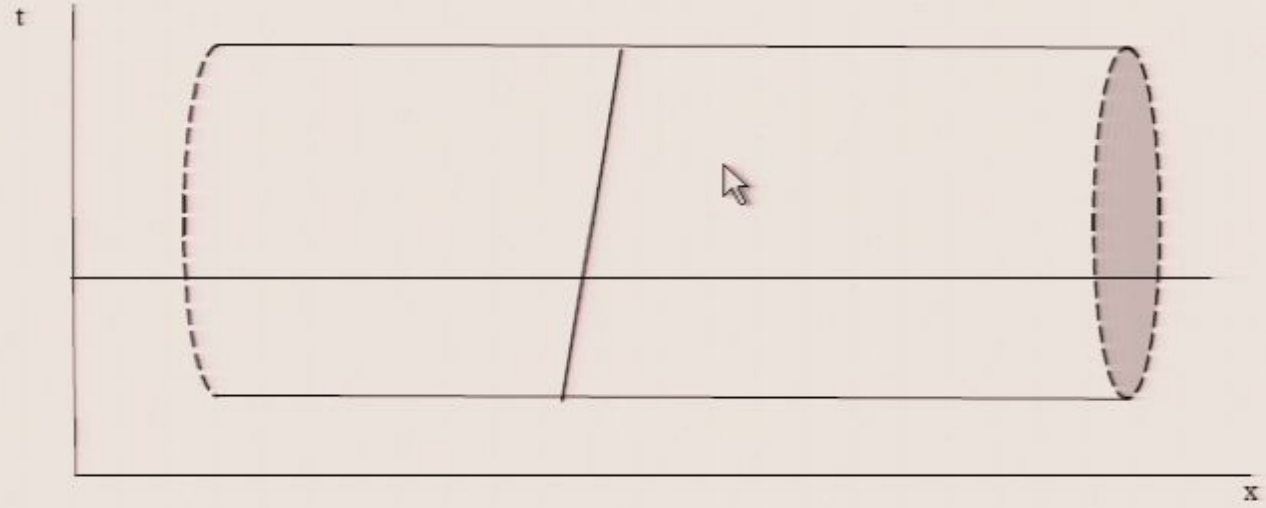
Nonlocal constraints

Spacetimes with closed timelike curves

- The initial state cannot be arbitrarily specified. This is impossible:



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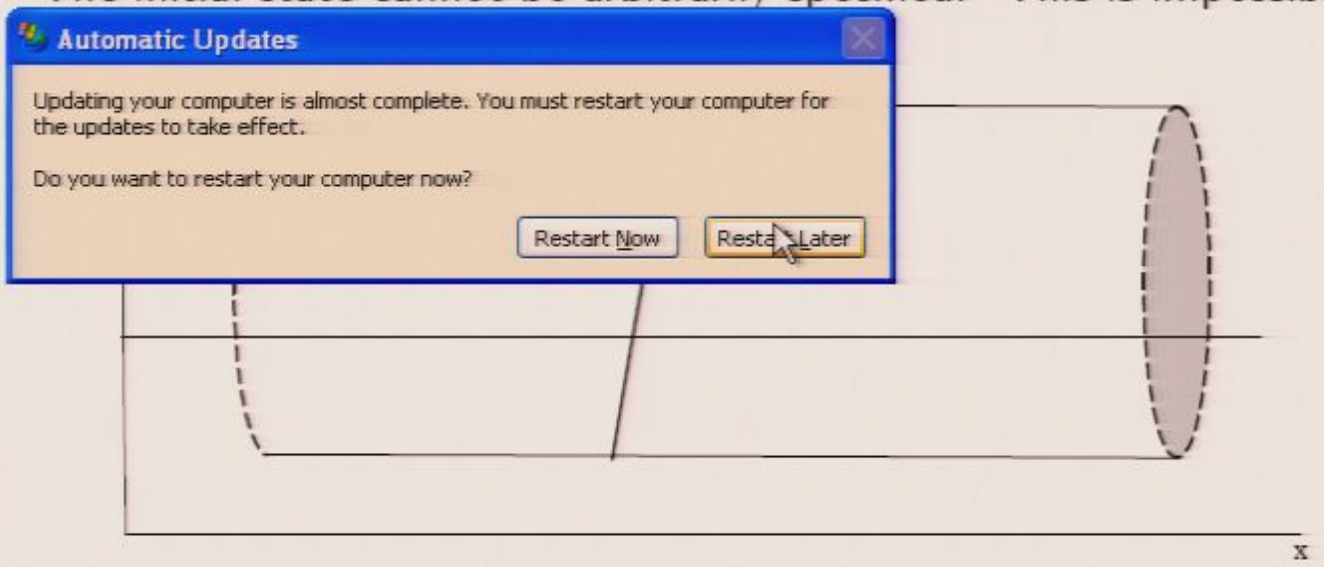

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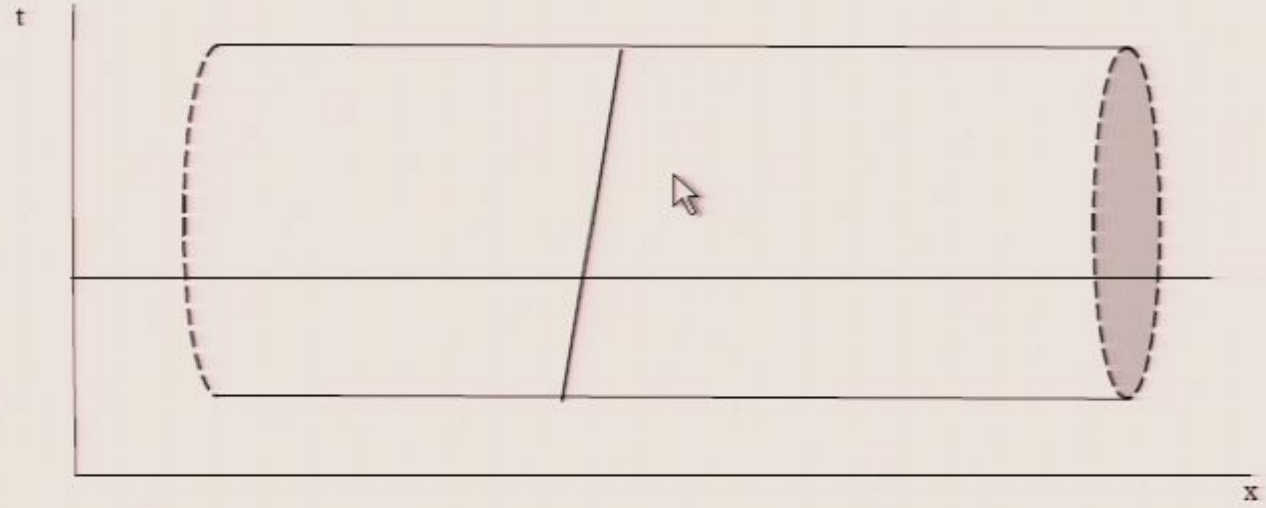

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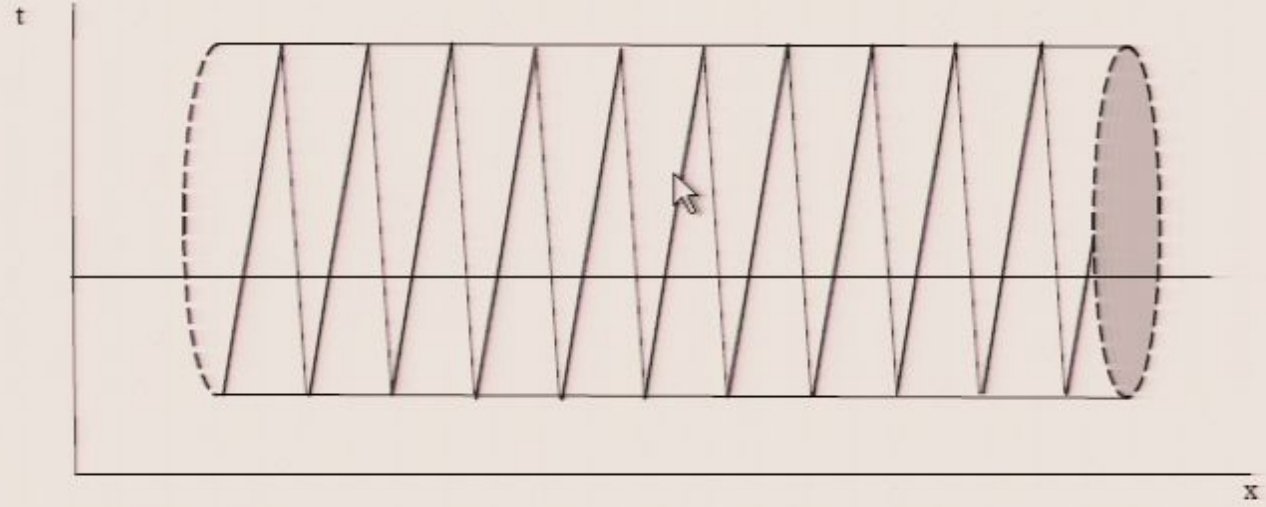

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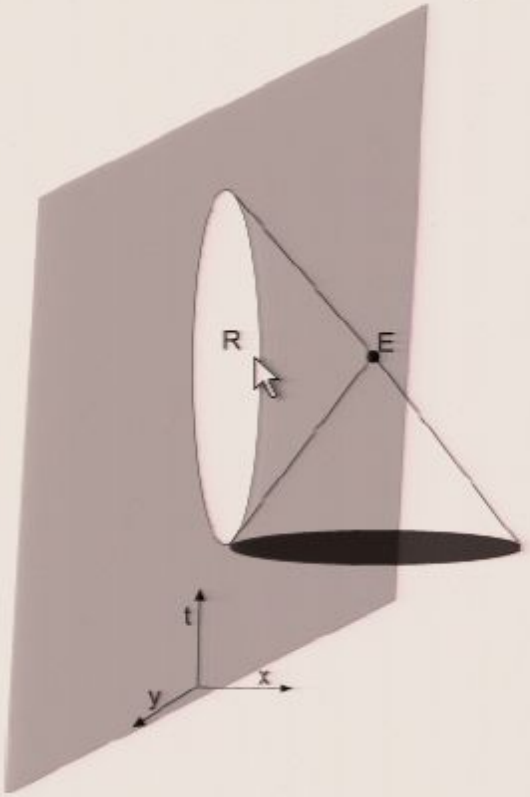

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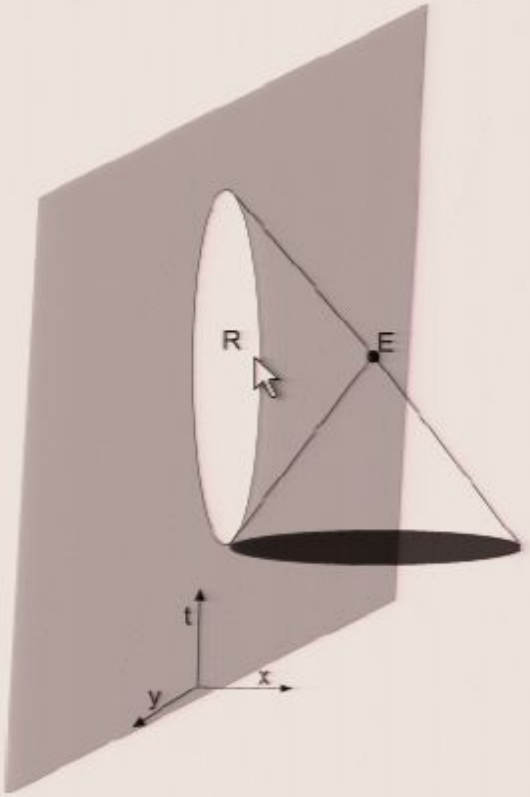

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Nonlocal constraints: Timelike initial data

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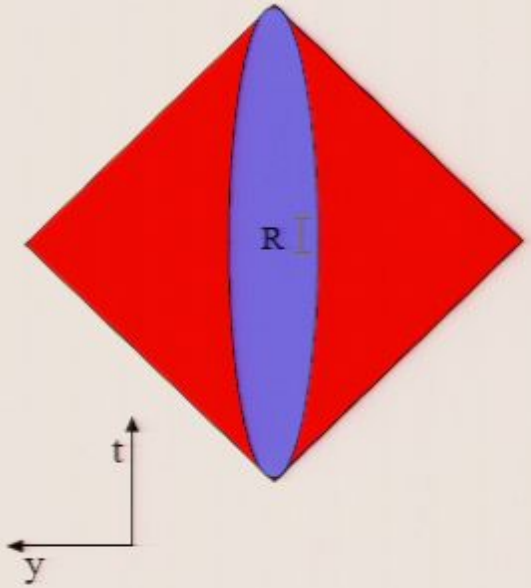

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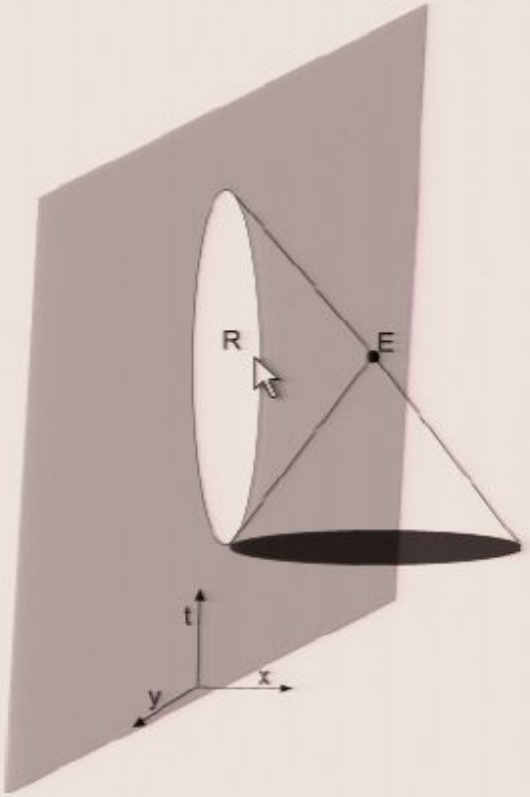

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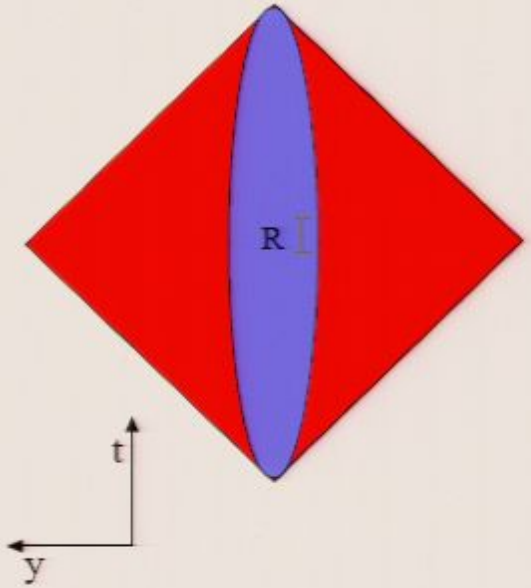

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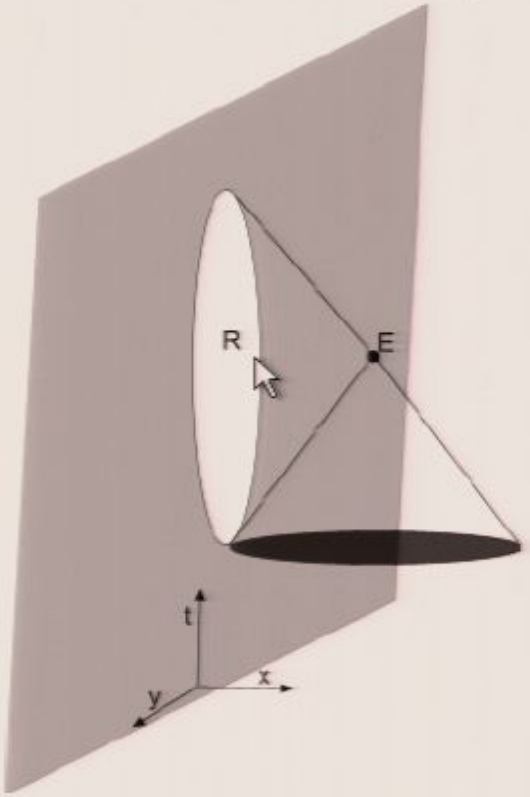

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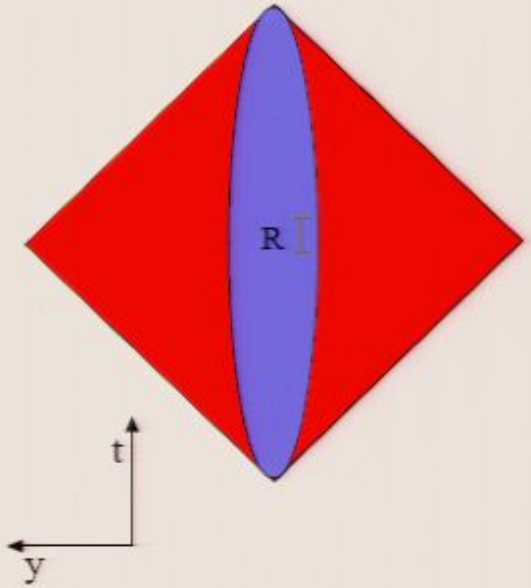

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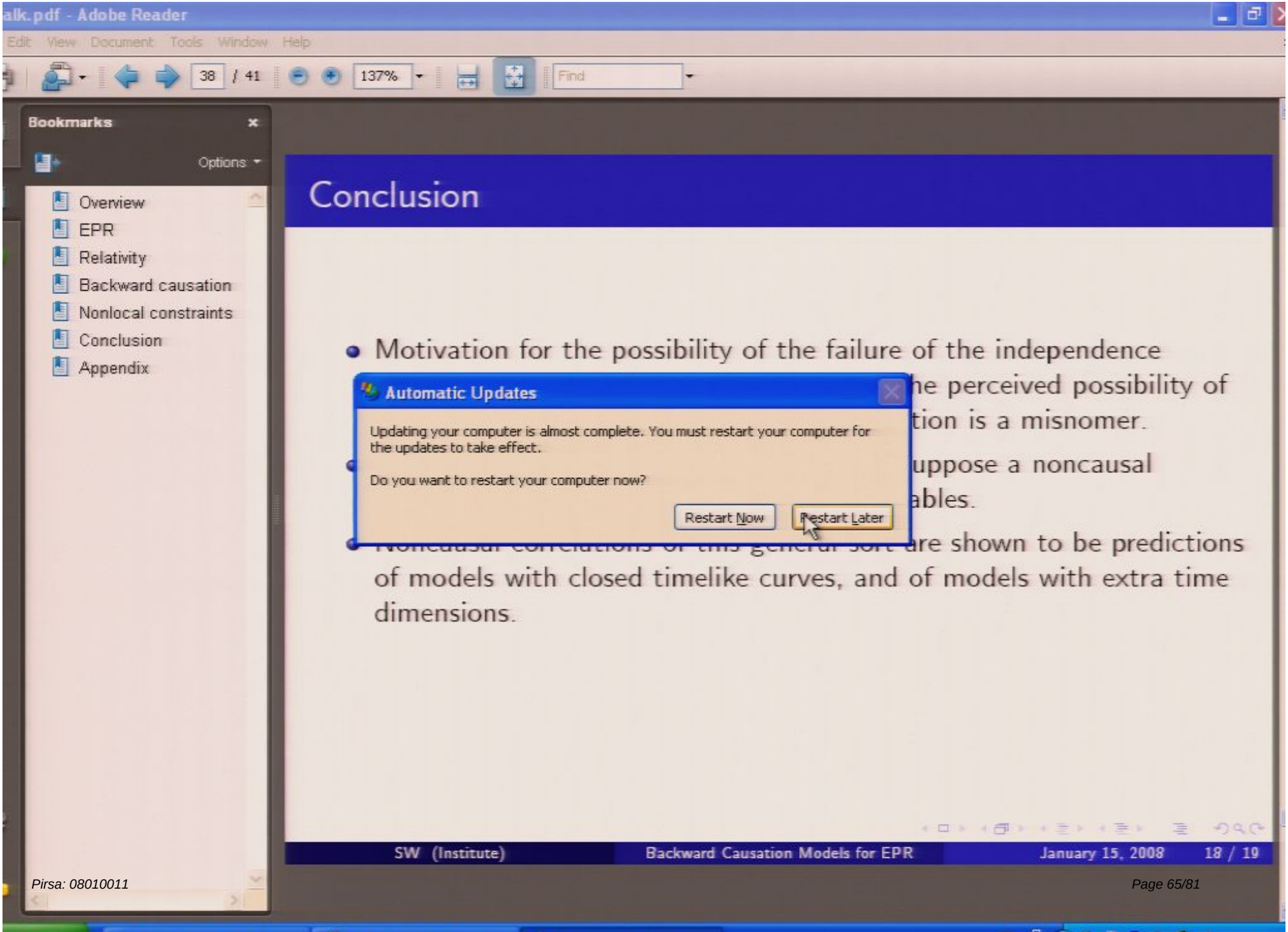
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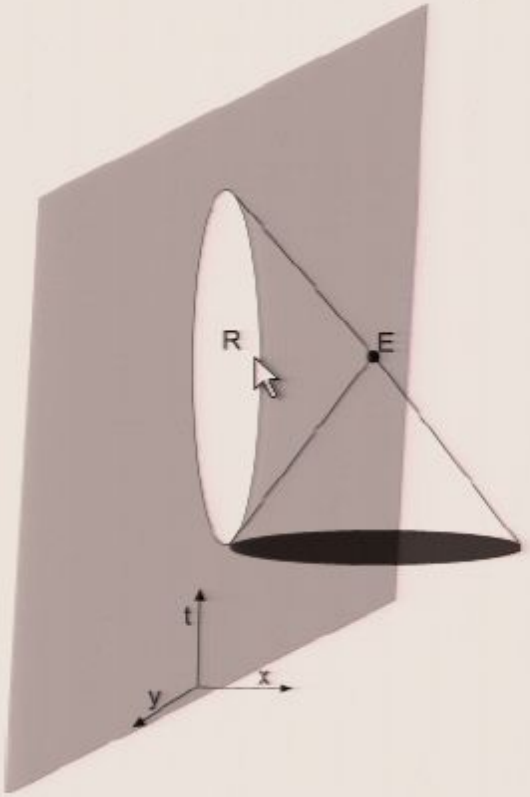
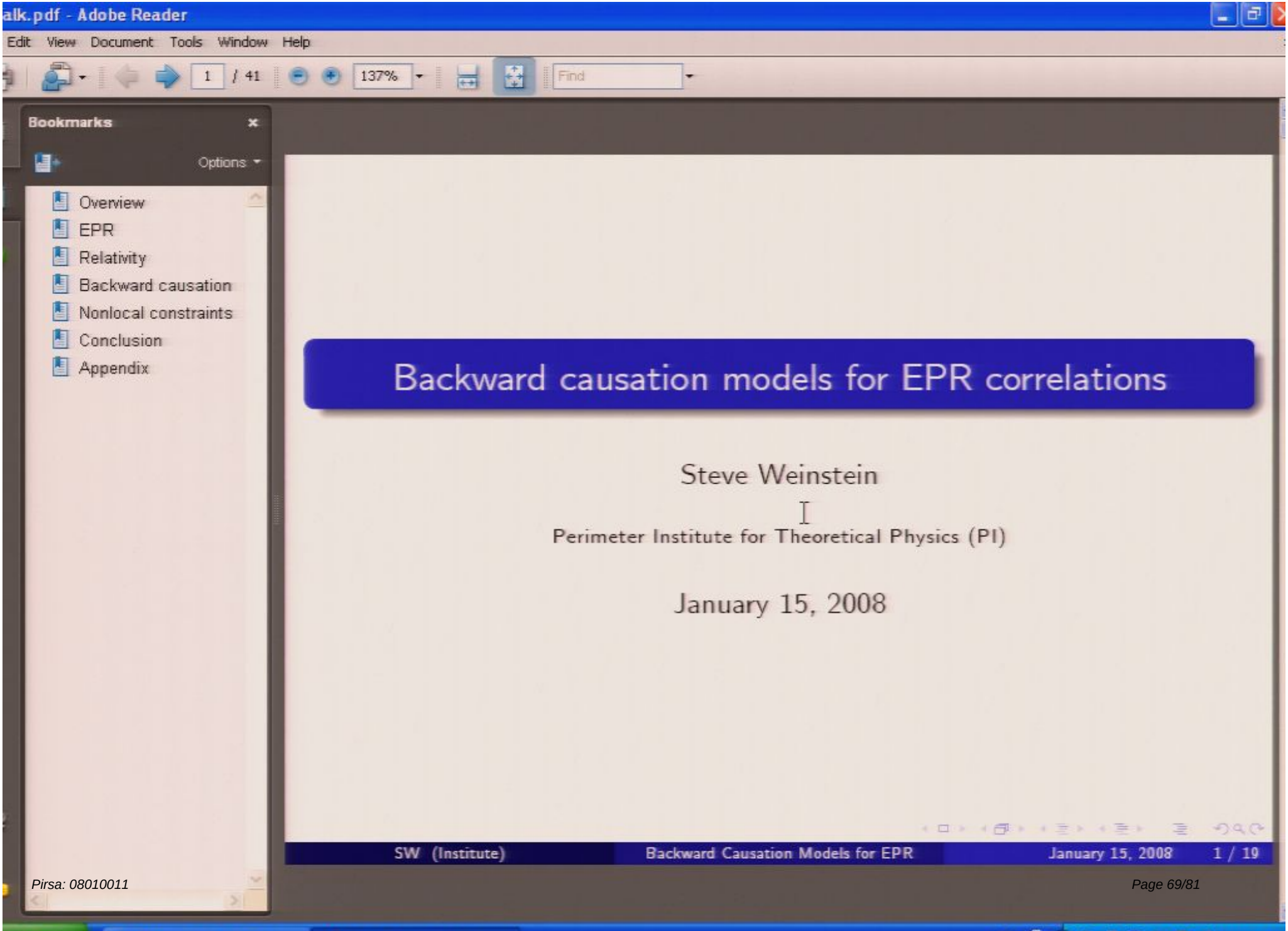


- Data in R (uniquely) determines data at E.

CHSH inequality

- CHSH inequality: $|E(a,b) - E(a,b')| + |E(a',b) - E(a',b')| < 2$
- The expression $E(a,b) = \int \rho(\lambda) A(a,\lambda) B(b,\lambda)$ assumes Bell-locality.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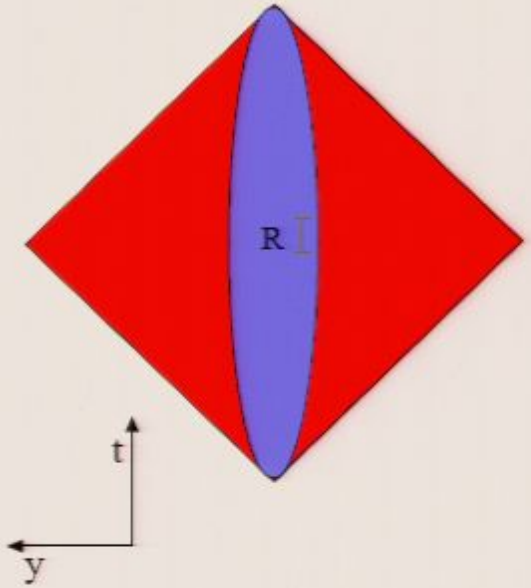

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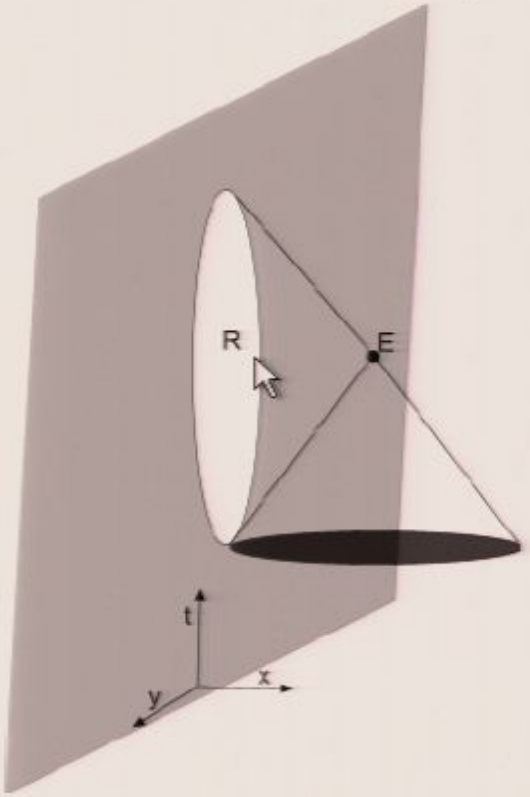

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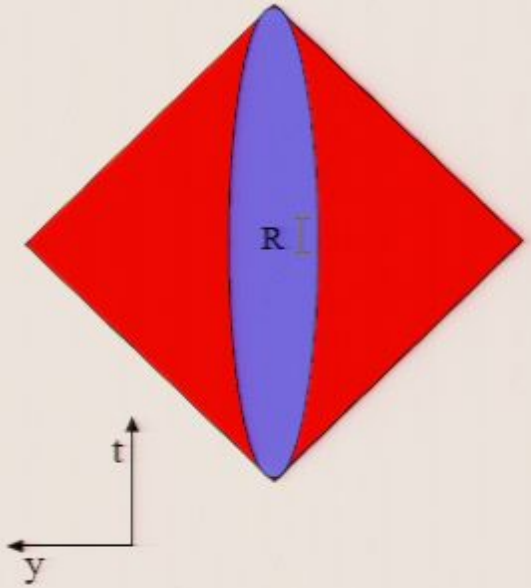

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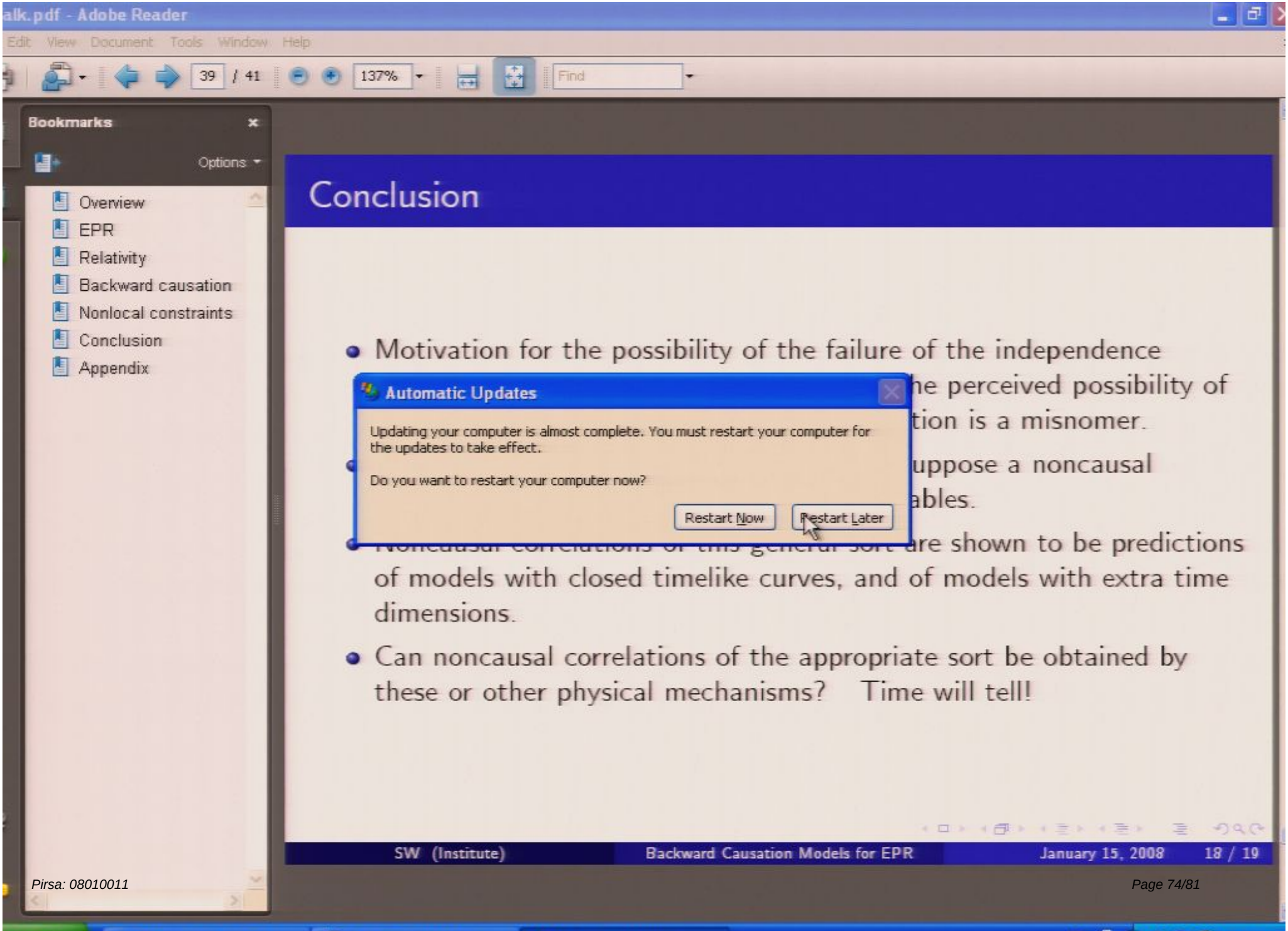
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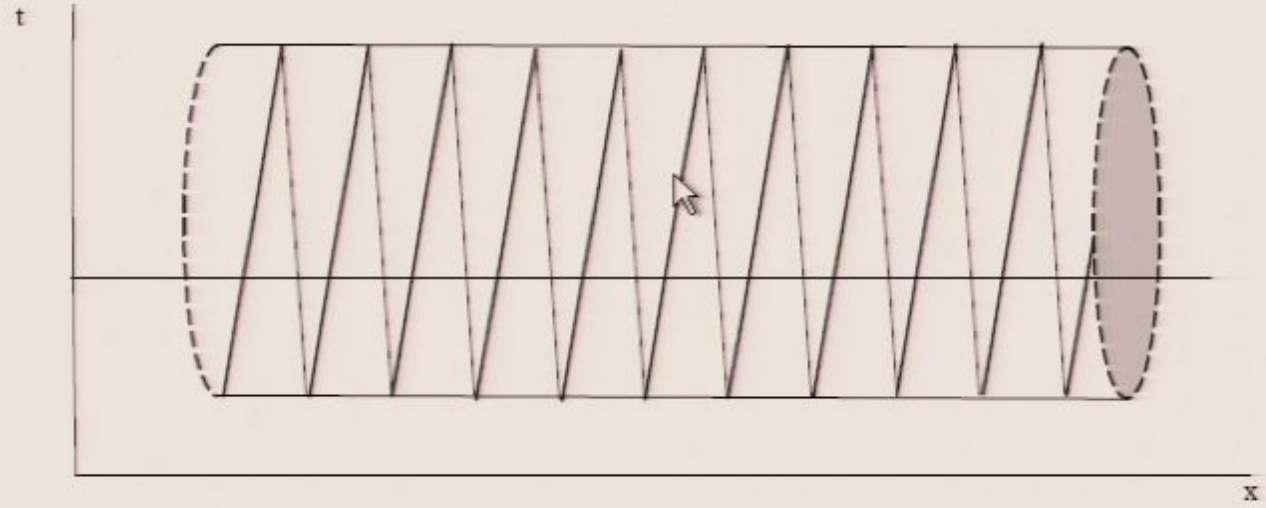

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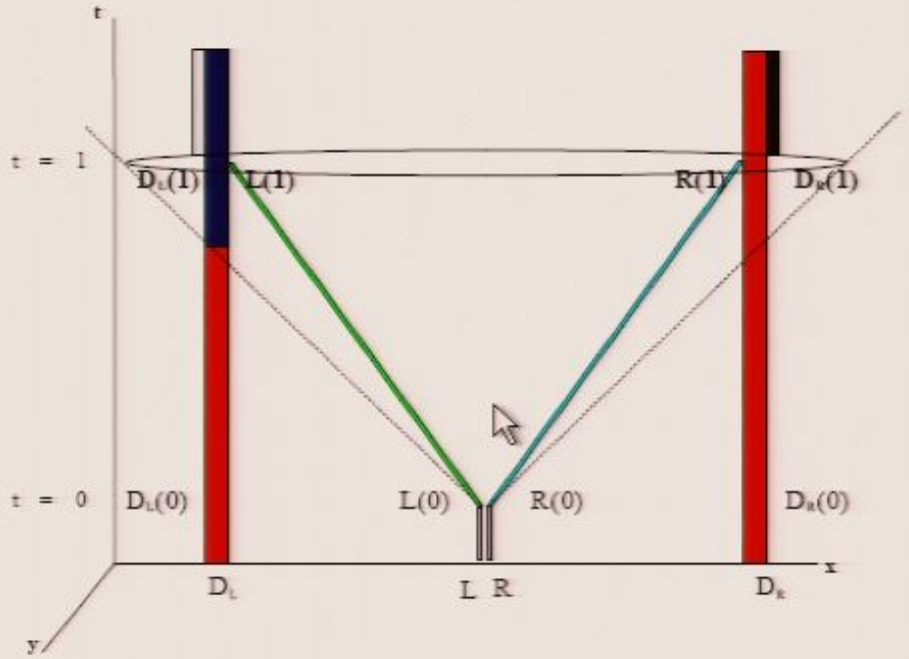

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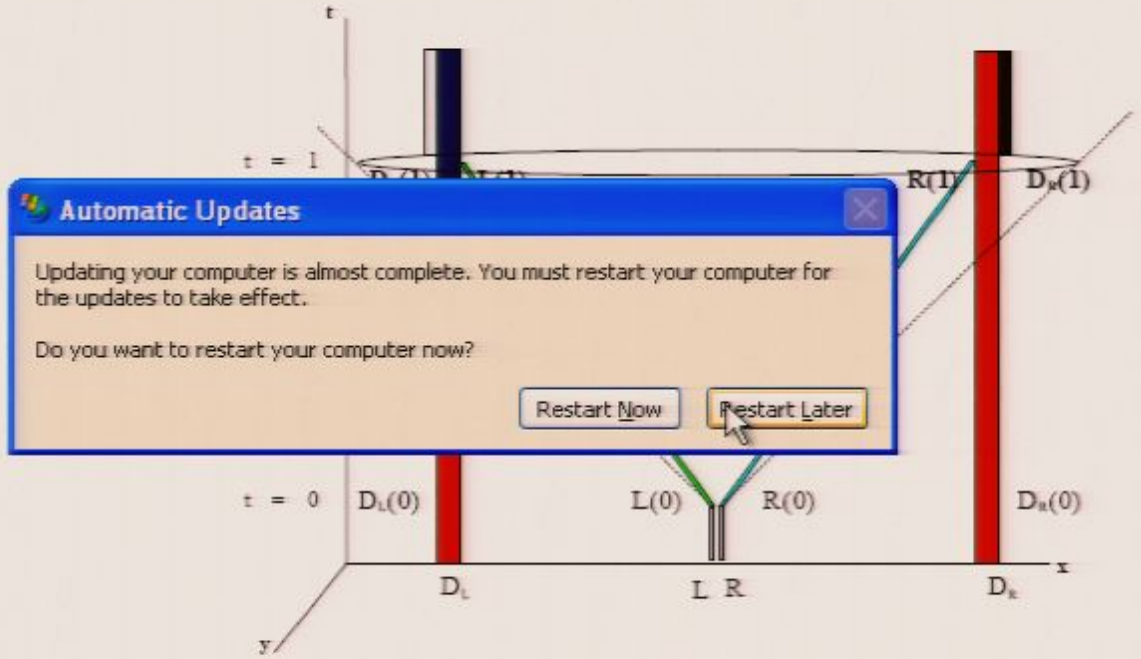

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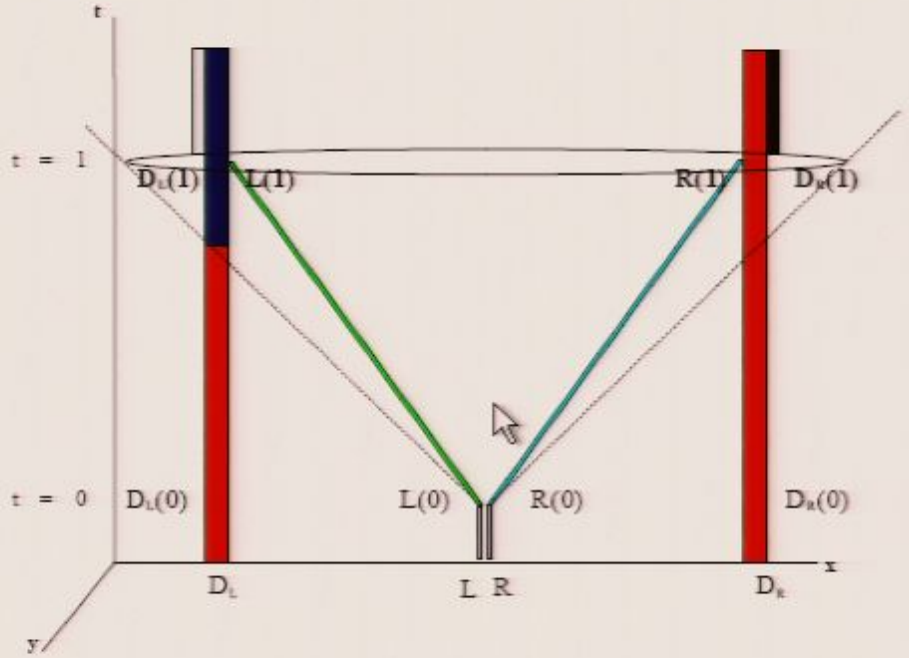

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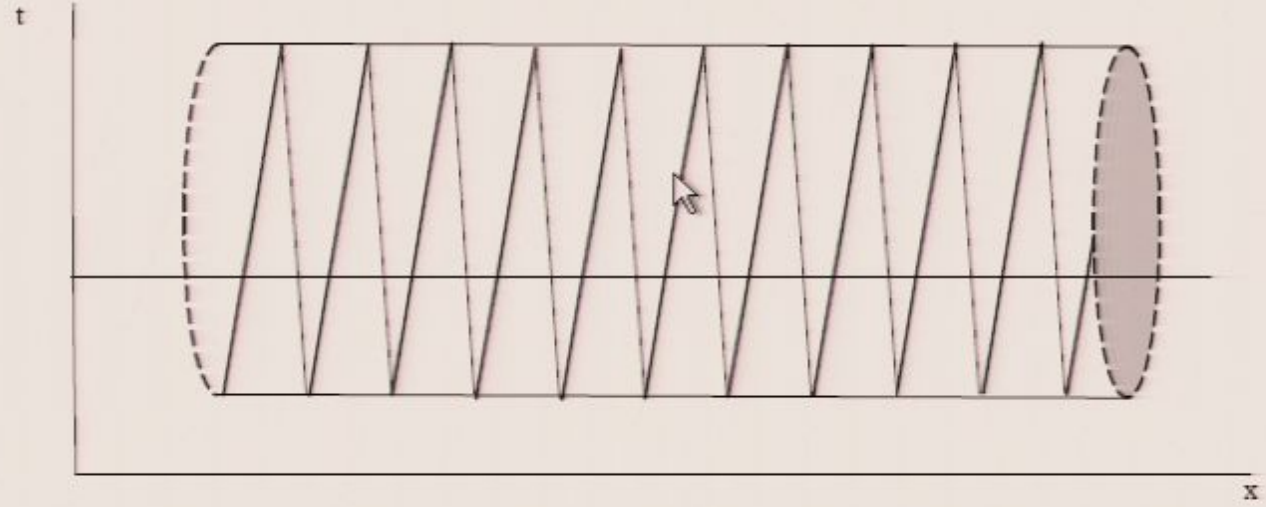

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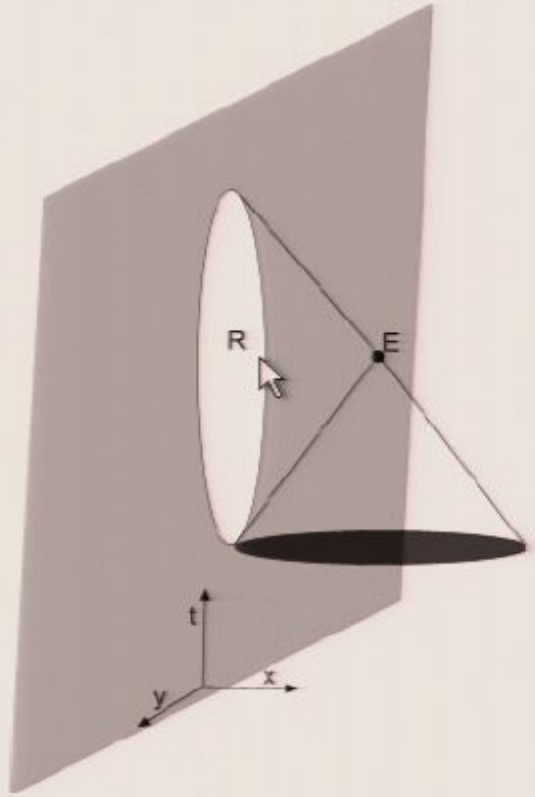

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