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Physics and Metaphysics: a Sellarsian project ... sort of

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KU LEUVEN

4 – Causality, or propagation and interaction

1. The source of the causality concept

From the experience of agency to the manipulation account

2. Is causality essentially a manifest image feature?

How to make the manipulation account ontic?

3. Physical causality: propagation and interaction

The quantum transference account

4. One or two causation?

What is the point?



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1. The source of causality

The origin of causality

“The basic premiss is that from an early age, we all have direct experience of acting as agents. That is, we have direct experience not merely of the Humean succession of events in the external world, but of a very special class of such successions: those in which the earlier event is an action of our own, performed in circumstances in which we both desire the later event, and believe that it is more probable given the act in question than it would be otherwise. To put it more simply, we all have direct personal experience of doing one thing and thence achieving another.” Menzies & Price 1993

The experience of agency is how we become aware of causation.

« [A]n event A is a cause of a distinct event B just in case bringing about the occurrence of A would be an effective means by which a free agent could bring about the occurrence of B. » Price and Menzies 1993

The formalization of these experiences is the starting point of the interventionist account of causality.



1. The source of causality

Judea Pearl's approach

In its general form, a functional *causal model* consists of a set of equations of the form $x_i = f_i(pa_i, u_i)$, $i = 1, \dots, n$, where pa_i (connoting parents) stands for the set of variables that directly determine the value of X_i and where the U_i represent errors (or “disturbances”) due to omitted factors.

The simplest type of external intervention is one in which a single variable, say X_i , is forced to take on some fixed value X_i . Such an intervention, which we call “atomic,” amounts to lifting X_i from the influence of the old functional mechanism $x_i = f_i(pa_i, u_i)$ and placing it under the influence of a new mechanism that sets the value x_i while keeping all other mechanisms unperturbed.



It is important to note that one of the goals of this formalization is to get rid of the notion of agent.



Woodward

If the experience of agency is the starting point of the interventionist account, this theory is not agent-centrist.

For example, the theory accommodates impossible interventions.

What is causation in the manifest image?
Best answer, the interventionist account.

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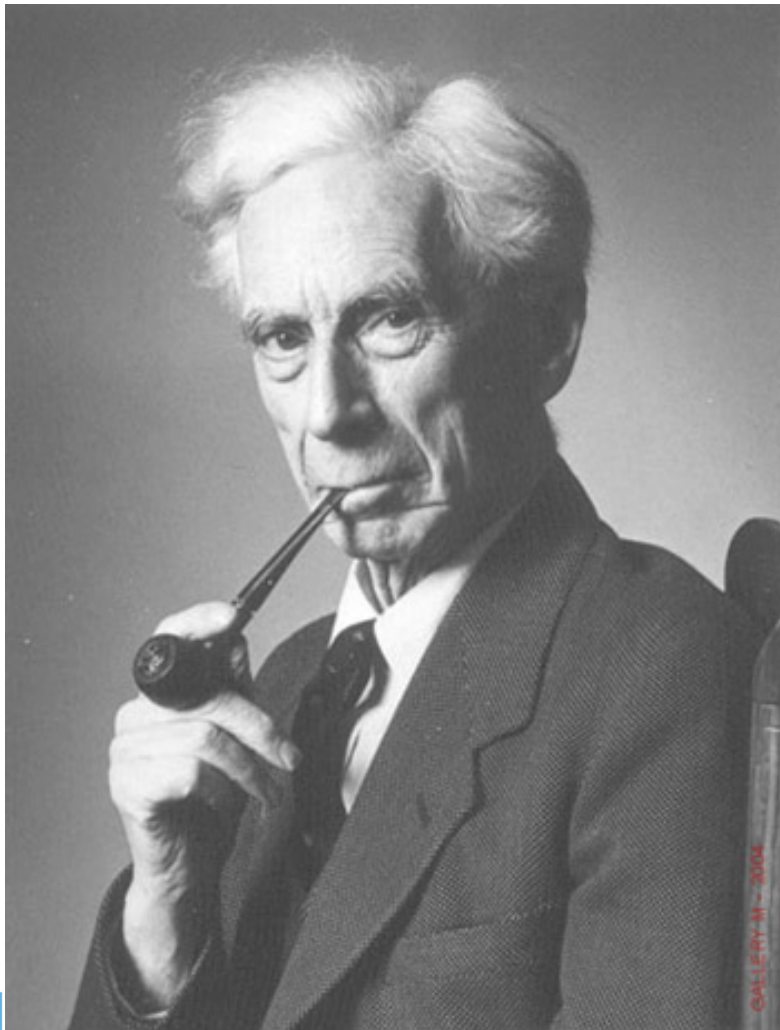
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2. Is causality essentially a manifest image feature?

But what about the scientific image? The interventionist account is useful in science but is such a causality constitutive of the scientific image?

According to Russell 1919:
« The law of causality [...] is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm. »

2. Is causality essentially a manifest image feature?

Russell style arguments against an ontic version of the interventionist causality (IC).

1 - IC is apparently directional, from the intervened event (parent variable) to the effect event (child variable).

Physical dynamics is not clearly directional. Rather it has interaction, in other words mutual influence.

2. Is causality essentially a manifest image feature?

2 – Even if IC does not include explicitly the notion of agent, it apparently still involves an active (disruptor) and a passive entity.

« For example, on Pearl's understanding of an intervention, in evaluating an interventionist counterfactual like "If X were to be changed by an intervention to such and such a value, the value of Y would change", we are to consider a situation in which the previously existing causal relationship between X and its causes is disrupted, but all other causal relationships in the system of interest are left unchanged." Woodward 2016

In physics, what would be an active or passive entity is unclear.



2. Is causality essentially a manifest image feature?

3 – The problem of scale

P1. If causal relations are the metaphysical explanation for regularities in nature then the same cause would always have the same effect (principle of causality).

P2. In a reductionist context, a macro-regularity (i.e. a regular biological or astronomical phenomenon) should be grounded in micro-causal relations.

P3. The relation between macro and microstates is one to many, many, many....

Conclusion. It is improbable that we can connect the well-known micro-causal relations with macro-regularities in order to realise the principle of causality.

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3. Physical causality: propagation and interaction



Ontic causality according to Salmon

- Causality is an objective feature of the world.
- Causal relations are contingent.
- Causality must be compatible with indeterminism.
- The theory must be independent of time (consistent with a causal theory of time).
- The theory should not violate Hume's structures concerning « hidden powers ». Dowe 1992

3. Physical causality: propagation and interaction

Transference theory

CQ1. A causal process is a world line of an object that possesses a conserved quantity.

CQ2. A causal interaction is an intersection of world lines that involves exchange of a conserved quantity.
(Dowe 2000, p. 90)

(S) Two events c and e are related as cause and effect if and only if there is at least one conserved quantity P , subject to a conservation law and exemplified in c and e , a determinate amount of which is transferred between c and e . (Kistler 2006, p. 26)

Difficulties

- Conserved quantities are well defined only in close systems.
- If the choice of conserved quantities is arbitrary, there is a risk that every processes are causal. If it is fixed, the theory is vulnerable to a theoretical change in physics.

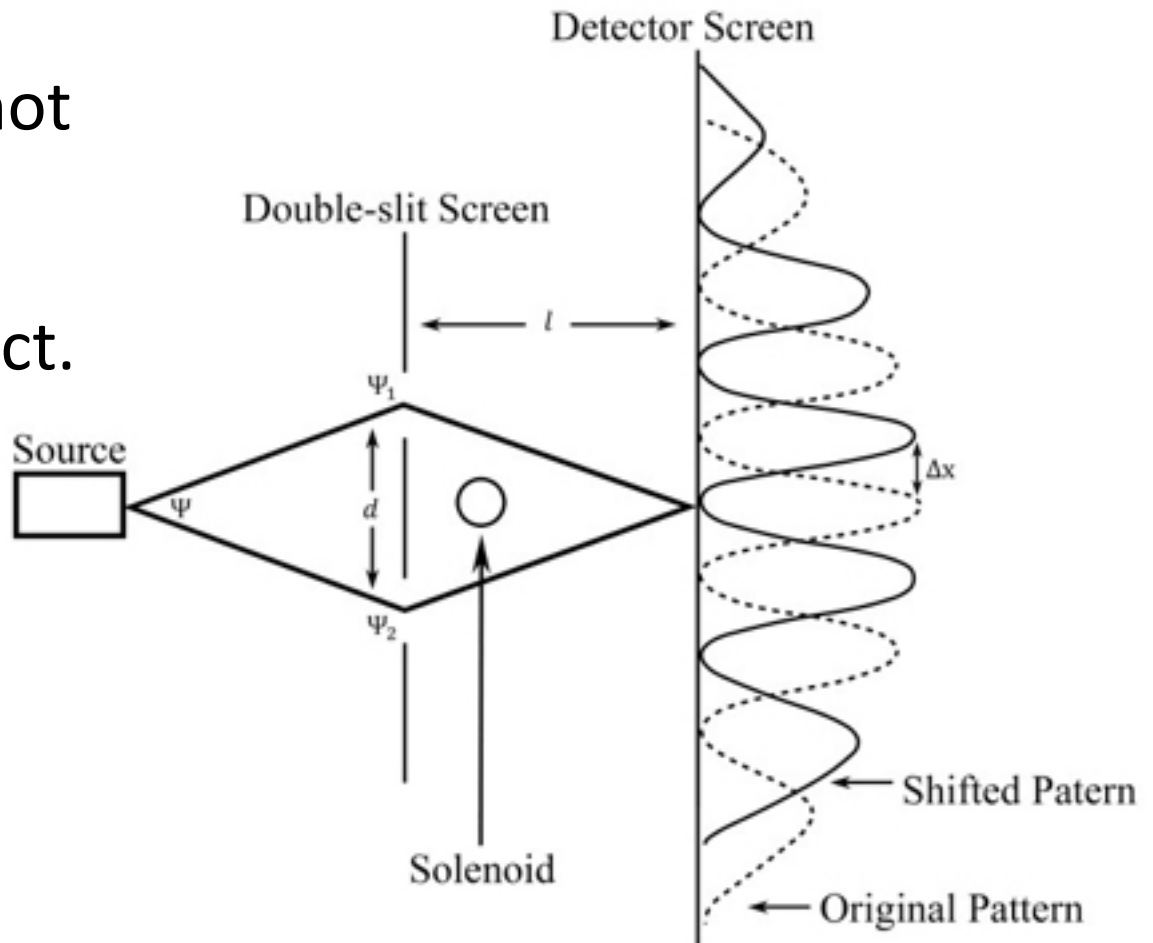
Difficulties

- Pseudo-processes – Process that apparently conserve or transmit a quantity by chance.
 - A fixed size shadow moving on a uniformly charged floor. According to Salmon, in this case, there is no genuine transmission even if there is conservation of charge.
- In QM, EPR correlations do not seem to be explainable by invoking a common cause. Nevertheless, they do not obey the transference theory of causality.
 - According to Kistler, they are not causal.
 - Retrocausality

3. Physical causality: propagation and interaction

The magnetic Aharonov-Bohm effect

Pedagogical setup, not
a real experimental
design to prove the
existence of the effect.



3. Physical causality: propagation and interaction

Using Feynman functional integral

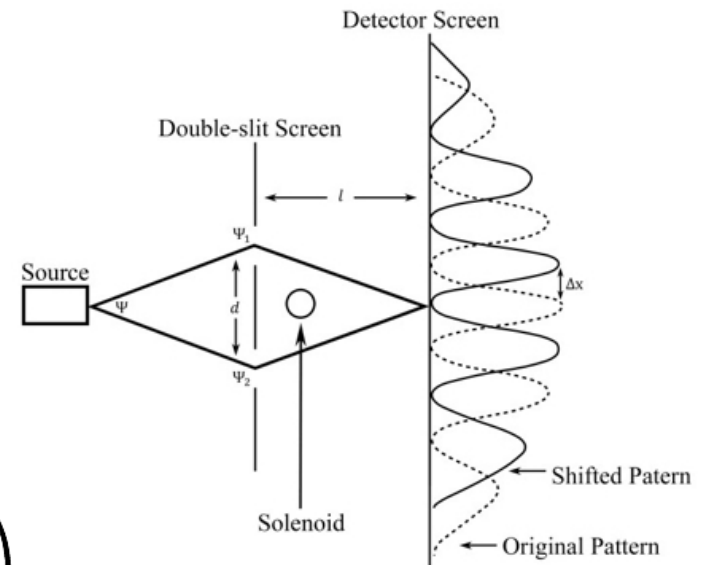
$$\langle out|in\rangle = \int D(\vec{q}(t)) e^{iS[\vec{q}(t)]}$$

Wilson line

$$U(out, in) = e^{-ie \int_q A_\mu dx^\mu}$$

Wilson loop

$$S(C) = \exp \left(-ie \oint_C \mathbf{A}(\mathbf{r}) \cdot d\mathbf{r} \right)$$



The AB effect is an electromagnetic phenomenon that has no classical equivalent.

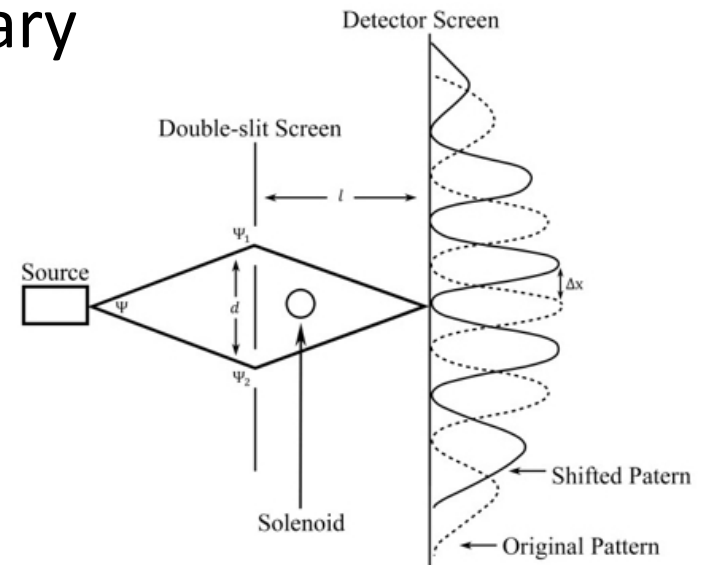
3. Physical causality: propagation and interaction

It can be shown that, in average, no transfer of energy or momentum is necessary for the effect to appear.

Is it causal?

Probably, because it can be used to transfer information.

However, information is not considered to be a directly causally relevant quantity, because there is no conservation law associated to it.



Ontic explanations of the effect

- The effect is the result of an action at a distance.
- The effect is the result of the local action of a local entity.
- The effect is the result of the local action of a non-local entity.



Ontic explanations of the effect

- The effect is the result of an action at a distance.
 - Fields were introduced to avoid action at a distance and reestablish local conservation of energy...
- The effect is the result of the local action of a local entity.
- The effect is the result of the local action of a non-local entity.



Ontic explanations of the effect

- The effect is the result of an action at a distance.
- The effect is the result of the local action of a local entity.
 - We have good reasons to believe that this option is not viable. Knowing the geometrical constraints (fibre space) of the system, there seems to be no clearly defined field that explain the effect (Guay 2008).
- The effect is the result of the local action of a non-local entity.

Ontic explanations of the effect

- The effect is the result of an action at a distance.
- The effect is the result of the local action of a local entity.
- The effect is the result of the local action of a non-local entity.
 - According to Healey (2007) Wilson loops represent non-local electromagnetic properties that would act locally.
 - If we adopt this option, even classical electromagnetism would be in a certain sense non-local.

Towards a new account of causation

1. We replace the transference theory by a theory of causality based on the notion of interaction. This step will already expand the domain of physical processes that should be considered causal. However, it will be a conservative extension. All previous cases of causal relations will remain causal.
2. We expand the interactionist theory to include a modal aspect that will provide a sufficient base to model quantum causal processes.

3. Physical causality: propagation and interaction

In order to have a common language between classical and quantum physics, we will frame this discussion in the Lagrangian formalism.

- Each system is characterised by Φ , the set of all possible histories. Φ includes the histories that satisfy and those that do not satisfy the dynamical equations (more on this on a subsequent slide).
- On this set we can define a functional, the action $S : \Phi \rightarrow \mathbb{R}$, that will determine all the dynamical properties of the system. Indeed, between an initial state in, a certain state at a certain time, and a final state out, the physical history, the one that actually takes place (if it exists), is the one minimising S .

3. Physical causality: propagation and interaction

- Let us assume that the dynamical equations are local in time, i.e. involving no time integrals and a finite number of time derivatives. In a relativistic theory, this implies that the equations are also local in space.
- These two points put strong constraints on what the action S could be. We will assume the common answer: S is the integral of the Lagrange function or Lagrangian, L , plus boundary terms (DeWitt, 2003).
- The Hamilton function $S(in, out)$ is defined as the value of the action on the physical history (if it exists) between in and out states, certain phase space states at certain specific times.

3. Physical causality: propagation and interaction

There are two kinds of possibilities involved in the Lagrangian formalism: kinematical and dynamical possibilities (Belot, 2007).

- Kinematical possibilities are possible histories of the system. They consist in all the ways to map dependent variables describing the states of system based onto independent variables. Together the kinematical possibilities form the set of possible histories Φ .
- The dynamical possibilities are a subset of the kinematical ones. They are the genuine physical histories. They are the possible histories that are compatible with dynamical laws.

3. Physical causality: propagation and interaction

For natural Lagrangians: L is equal to the difference between kinetic and potential energy.

CQ1'. A causal process is a continuous (or almost continuous) series of spacetime events governed by kinetic terms in L , conserving basic quantities, like energy.

CQ2'. A causal interaction is a way the causal processes can interact with each other. This interaction is governed by the interaction terms of L .

3. Physical causality: propagation and interaction

N mass points interacting via the Newtonian gravitational force

$$L = \sum_{i=1}^N \frac{m_i v_i^2}{2} - \sum_{1 \leq i < j \leq N} \frac{G m_i m_j}{\| \vec{r}_i - \vec{r}_j \|}$$

- According to CQ1', the kinetic terms determine what are the causal processes between interaction or more generally in the absence of interaction.
- According to CQ2', the interaction terms determine how the causal processes are transformed. In this case all interactions are symmetric.

What about Lagrangians that are not natural, like the Einstein-Hilbert Lagrangian or the pure Chern-Simons Lagrangian?

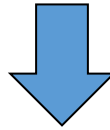
Our understanding is that in these cases causal interpretation is difficult independently of the conception of causality assumed.



3. Physical causality: propagation and interaction

Quantum case

Hamilton function on phase initial data space



Transition amplitudes in an Hilbert space

Feynman functional (DeWitt notation)

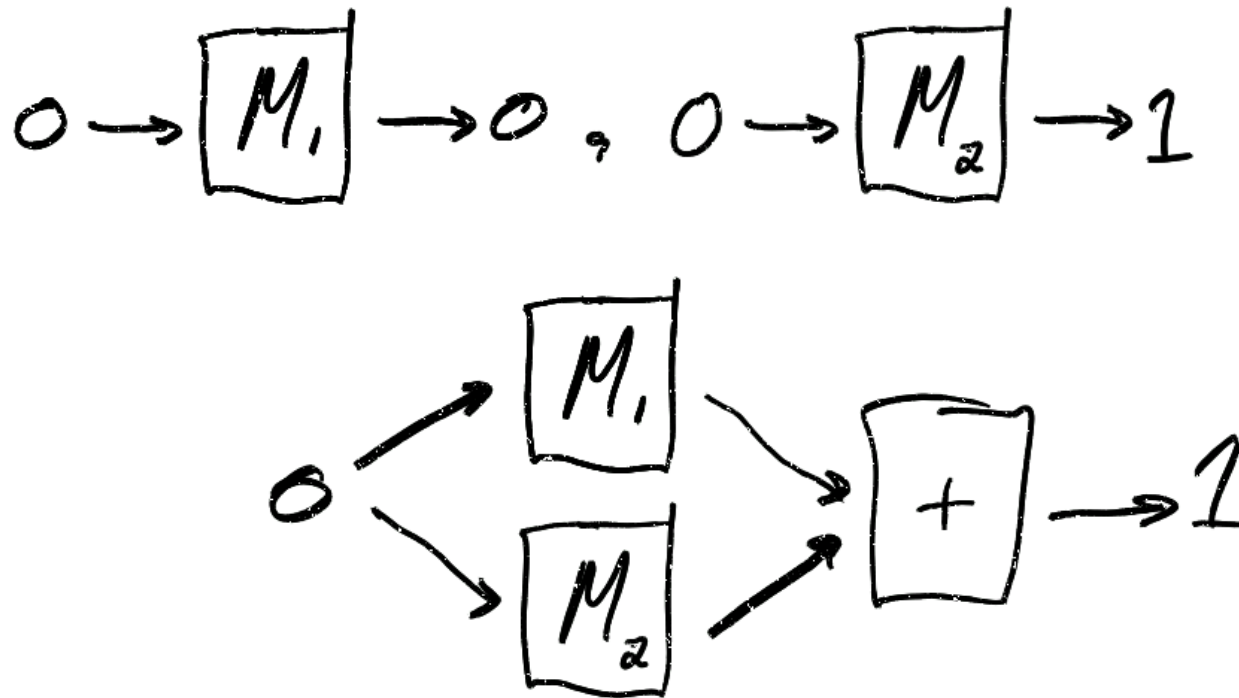
$$\langle out|in\rangle = \int e^{iS[\varphi]} \mu[\varphi][d\varphi], \quad [d\varphi] := \prod_i d\varphi^i$$

The classical Lagrangian is in S.

Can we generalise our analysis of classical causality? Yes
but non dynamical possibilities must be taken into
account.

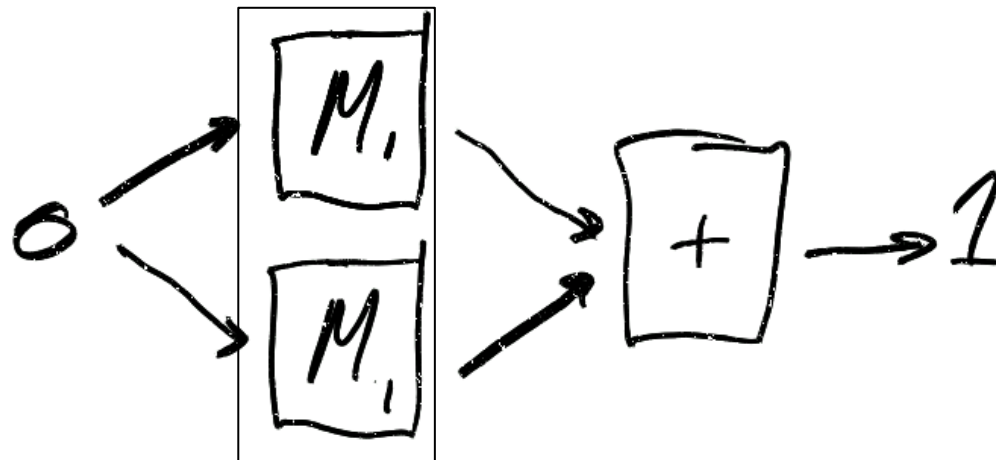
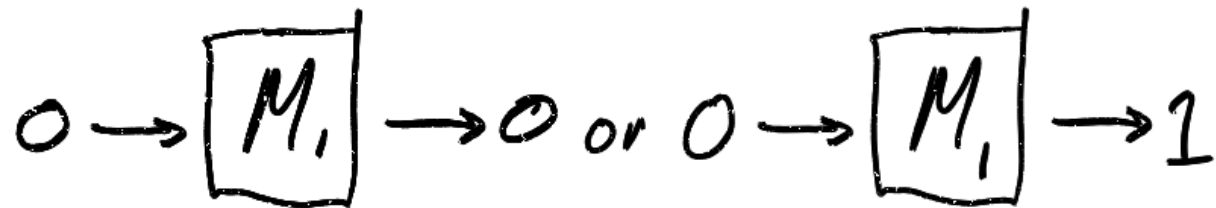
An analogy

Interaction between two actually distinct classical causal processes.



3. Physical causality: propagation and interaction

Interaction between two distinct classically possible processes.



3. Physical causality: propagation and interaction

Back to the AB effect

Feynman functional

$$\langle out|in\rangle = \int D(\vec{q}(t)) e^{iS[\vec{q}(t)]}$$

The electromagnetic contribution to each history:

$$U(out, in) = e^{-ie \int_q A_\mu dx^\mu} \quad \text{No classical effect.}$$

The difference between two histories:

$$S(C) = \exp \left(-ie \oint_C \mathbf{A}(\mathbf{r}) \cdot d\mathbf{r} \right)$$

The non locality is the result of the integration of different local histories, not of the local effect of non-local entities.

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4. One or two kinds of causation

Two conceptions of causality:

- ❑ *Transference causality*. Potentially part of the ontology of the scientific image.
- ❑ *Interventionist causality*. Potentially part of the ontology of the manifest image, even the part concerning scientific activities.

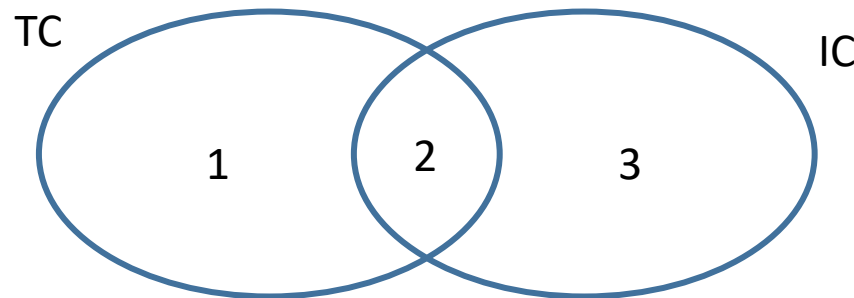
How to articulate these two conceptions?



4. One or two kinds of causation

Possibilities

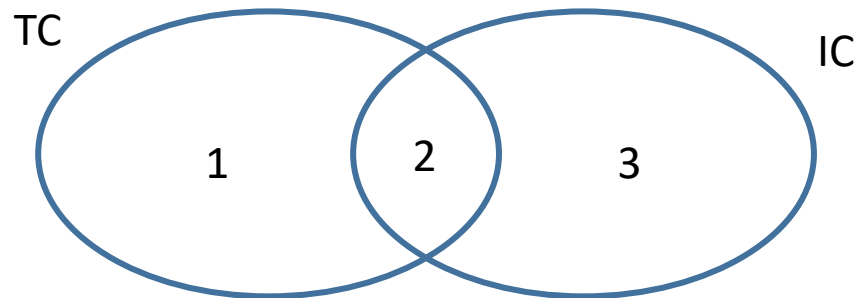
- ❑ If the two concepts were clearly distinct, 2 would essentially be empty. This is not the case. For example, many cases of propagation can be modelled as compatible with IC.
- ❑ IC cannot be reduced to TC. 3 is not empty. For example, “I did not water my plant. It died. therefore my action is the cause of its death” is a causal relation that cannot be included in the framework of TC.



4. One or two kinds of causation

Possibilities

- If IC is sufficiently flexible, most, if not all, cases of TC are also cases of IC. 1 is empty or almost empty.



TC relations explain why the associated IC cases hold. In these cases, we could say the IC relation holds *in virtue of* the TC relation. But not all IC relations are grounded in that way.

Still, IC would be the more appropriate conception of causality in order to act efficiently.

In the case of causality, the manifest and the scientific image are and will stay distinct but related.



Vincent Ardourel