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Causality in Action Theories

Summary of the article

Causal reasoning has become very important in the last few years in logic based action theories. In this article, we study how causal inference has been integrated and used in action theories.

We discuss criteria representing properties which might be desirable for causal implication, such as reasoning by case, to give an example. But there are also criteria representing properties which causal implication should not have. The criteria are discussed independently on the language level on which causal implication (or the causality relation) is represented.

We present four formalisms which are approaches to actions and causality and we try to situate each formalism in relation to the criteria.

Criteria for causality

We will try to situate each formalism in relation to the following criteria, considered as meaningful for causality.

1. Monotonicity
   Classical implication " $\rightarrow$" is monotonic. This means that from $\phi \rightarrow \psi$, we can conclude $\phi \wedge \chi \rightarrow \psi$. But the same is not so obvious for causal implication. To give an example:
   If it rains, then John will get wet clothes. If it rains and John has an umbrella, he will *not* get wet clothes. So, we have

   rain CAUSES *wet* but not necessarily *rain*$\wedge$*umbrella* CAUSES *wet*

2. Transitivity
   The classical implication is transitive. This means that from $\phi \rightarrow \psi$ and $\psi \rightarrow \chi$, we conclude $\phi \rightarrow \chi$. Arguments can be found for supporting both, that causality is transitive or that it is not transitive.

3. Contraposition
   Classical implication is contrapositive. This means that from $\phi \rightarrow \psi$ is true, we can conclude that $\neg\psi \rightarrow \neg\phi$ is true. Causality is certainly *not* contrapositive, as illustrates the following example.
   "If the sun is shining, I will go to the beach" might be true. But it is possible that I do not go to the beach, however the sun is shining. Hence the contraposition "if I do not go to the beach, then the sun is not shining" might not be true!!

4. Reflexivity
Classical implication is reflexive, we have that $\phi \rightarrow \phi$ is true for any ϕ. But causality should not be reflexive. Nothing can cause itself!

5. Conjunction of preconditions
For classical implication, if $\phi \wedge \pi \rightarrow \psi$ is true, then either $\phi \rightarrow \psi$ or $\pi \rightarrow \psi$ is true. This does not hold for causal implication as shows the following example:
If I am in the bain tub and I use the hair dryer, this causes a danger for my life. But neither one of these facts alone causes a danger for my life. If somebody is in his bain tub, normally there is no danger for his life, neither if he uses a hair dryer.

   The following are properties which a causality relation should have.

6. Conjunction
Just as for implication, if a fact causes two other facts, it should cause their conjunction. Thus we should have

$$if\ \phi \text{ CAUSES } \psi \text{ and } \phi \text{ CAUSES } \pi \text{ then } \phi \text{ CAUSES } \psi \wedge \pi$$

7. Reasoning by case
A causal relation should allow for reasoning by case. We think $\phi \vee \pi$ CAUSES ψ should be true, whenever ϕ CAUSES ψ and π CAUSES ψ are true.

   For an example, if John's right arm is broken, he cannot work any more. If John's left arm is broken, he cannot work neither. We know that either his left or his right arm is broken and we want to conclude that he cannot work any more.

8. Right weakening RW
We think that a formula should cause all logical consequences of the formulas it causes, i.e. if ϕ CAUSES ψ and $\models \phi \rightarrow \chi$, then ϕ CAUSES χ. This is a specific form of the well known rule RCK which holds for all systems of conditional logic. This rule holds also for cumulative and preferential logics and has been used (and called "right weakening") by Sarit Kraus, Daniel Lehmann and Menachem Magidor in [4, 5].

9. Left logical equivalence LLE
Classically equivalent assertions should have the same causal consequences. This is the well known rule RCEA of conditional logic. A more special form of this rule has been used (and called "left logical equivalence") for cumulative and preferential logics [4, 5].

   If ϕ CAUSES ψ and $\models \phi \leftrightarrow \chi$ then χ CAUSES ψ.

Approaches to Actions and Causality

We will discuss in greater detail four approaches.

1. Fangzen Lin in [7, 8] presents a theory for actions and causality which is based on classical predicate logic with circumscription. The causality relation $f\ CAUSES\ g$ is represented by a formula $Holds(f, s) \rightarrow caused(g, v, s)$, meaning "if f is true in the situation s, then g is caused to be v, where $v \in \{true, false\}$, in the situation s.

2. Norman McCain and Hudson Turner in [9, 10], represent causality by means of a conditional type operator $\Rightarrow$. ϕ $CAUSES$ ψ is represented by a formula $\phi \Rightarrow \psi$. A special semantics is defined for specifying what are the consequences of a set of causal rules of this form. Lifschitz in [6] generalizes this notion of causality (for first-order formulas ϕ and ψ. One extension opf the action description language A [2] is based on this theory.

3. Michael Thielscher in [11] uses causal rules of the form l $CAUSES$ l' if $\bigwedge_i l_i$, where l, l' and l_i are literals. These rules are generated automatically from clauses by means of *influence information*.

4. Laura Giordano, Alberto Martelli and Camilla Schwind in [1] use a unary modal operator ⓒ for expressing that a formula is caused. ϕ CAUSES ψ is expressed by $\phi \rightarrow$ ⓒψ, meaning "if ϕ holds, then ψ is caused".

Resuming tableau

The following table resumes the results of study. We expect that the five first properties do not hold for causal implication whereas the four last properties should hold.

Criteria	Lin	MT cons	MT $\Rightarrow$	Thiel	GMS
Monotonicity	yes	no	yes	-	yes
Transitivity	yes	yes	yes	no	no
Contraposition	no	yes	no	no	no
Reflexivity	no	-	no	no	no
Conj. of prec.	yes	-	no	-	yes
AND	yes	yes	yes	-	yes
OR	yes	-	yes	-	yes
RW	-	yes	yes	-	yes
LLE	yes	-	yes	-	yes

MT cons stands for McCain and Turner's consequence relation, Thiel for Thielscher's and GMS for Giordano, Martelli and Schwind. We filled in "yes" whenever the respective theory admits the property and "no" if not. In the cases where the property is not expressible, we put -. It is worth observing that we did not meet any ideal theory admitting all the properties we thought it should and not admitting non one of those it should not.

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