Explaining actual causation in terms of possible causal processes

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Type causality
“Smoking causes cancer”

Actual causality
“The cars faulty brakes caused the crash”

Formalizing actual causation

What does it mean to say:

C caused E?

Content

1. Actual Causality: Structural Equations and Counterfactual Reasoning
2. Our Approach to Actual Causality
3. Conclusion

The counterfactual approach

- Lewis (1973):

  C caused E := “Without C, E would not have been”

- Pearl (2000)
- Halpern & Pearl (2001, 2005) (HP)
- Halpern (2016), Fenton-Glynn (2015), Gerstenberg (2015), Vennekens (2011), …
- Counterfactual definitions of actual causation in the context of structural equation models.

Example

Suzy and Billy both pick up rocks and throw them at a bottle. Suzy's rock gets there first, shattering the bottle. Since both are expert rock-throwers, Billy's would have shattered the bottle had it not been preempted by Suzy's throw.

$$\begin{aligned} \mathit{Shatter} &:= \mathit{SuzyHits} \vee \mathit{BillyHits} \\ \mathit{SuzyHits} &:= \mathit{SuzyThrows} \\ \mathit{BillyHits} &:= \mathit{BillyThrows} \wedge \neg \mathit{SuzyThrows} \end{aligned}$$

World: $\mathit{SuzyThrows} = \mathit{BillyThrows} = \mathbf{t}$. What are the actual causes of Shatter?

Definition (Halpern, 2016)

$\bar{X} = \bar{x}$ is an actual cause of ϕ in $(M, \bar{u})$ if:

- $\bar{X} = \bar{x}$ and ϕ both hold in the world $(M, \bar{u})$
- There is a set of variables W such that if we fix their value and change X's value, ϕ no longer holds
- $\bar{X}$ is a minimal such set

Example

$$\begin{aligned} \mathit{Shatter} &:= \mathit{SuzyHits} \lor \mathit{BillyHits} \\ \mathit{SuzyHits} &:= \mathit{SuzyThrows} \\ \mathit{BillyHits} &:= \mathit{BillyThrows} \land \neg \mathit{SuzyThrows} \end{aligned}$$

In world $\mathit{SuzyThrows} = \mathit{BillyThrows} = \mathbf{t}$, *SuzyThrows* is an actual cause of *Shatter*:

- Contingency set $W = \{\mathit{BillyHits}\}$
- If Suzy does not throw under this intervention, the bottle does not shatter

Criticisms against counterfactual definitions

- Objections against counterfactual approach

  Alternative definitions

  Hall (2004), Baumgartner (2013), Bochman & Lifschitz (2015)

- Problematic causal scenarios for all counterfactual definitions
  $\Rightarrow$ Refinements of the definitions

Criticisms against counterfactual definitions

Halpern (2016b) analyzes 6 of these problematic causal scenarios.
$\rightarrow$ different informal interpretation of the same formal model
$\rightarrow$ HP correct under that interpretation!

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Halpern (2016b) analyzes 6 of these problematic causal scenarios.
$\rightarrow$ different informal interpretation of the same formal model
$\rightarrow$ HP correct under that interpretation!
Thus... causal models are ambiguous! Some knowledge is missing.

Ambiguities (Example 1, Scenario 1)

- Two deadly potions (Arsenic, Strychnine)
- They work independently

$$\mathit{Dead} := \mathit{Strychnine} \vee \mathit{Arsenic}$$

Ambiguities (Example 1, Scenario 2)

- Two deadly potions (Arsenic, Strychnine)
- But... Arsenic preempts the chemical process by which Strychnine poisoning works

$$Dead := (\neg Arsenic \wedge Strychnine) \vee Arsenic$$

Equivalent to:

$$Dead := Strychnine \vee Arsenic$$

Resolving the Ambiguitiy (Halpern)

- KR methodology: reify mechanisms by auxiliary variables

$$\mathit{Dead} := \mathit{SPoising} \vee \mathit{Arsenic}$$
$$\mathit{SPoisining} := \neg\mathit{Arsenic} \wedge \mathit{Strychnine}$$

- Works: gets the right answers, but...
- no principled explanation of actual causation in terms of the causal process and mechanisms

Ambiguities (Example 2)

An assassin may kill a victim by administering deadly poison. A bodyguard may rescue the victim by administering an antidote.

$$\mathit{Dead} := \mathit{Poison} \land \mathit{NoAntidote}$$

Ambiguities (Example 3, Scenario 1)

Halpern (2016b)

> *"There are four endogenous binary variables, A, B, C, and S, taking values 1 (on) and 0 (off). Intuitively, A and B are supposed to be alternative causes of C, and S acts as a switch. If S = 0, the causal route from A to C is active and that from B to C is dead; and if S = 1, the causal route from A to C is dead and the one from B to C is active."*

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$$C := (\neg S \wedge A) \vee (S \wedge B)$$

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$$C := (\neg S \wedge A) \vee (S \wedge B)$$

What is the actual cause of C, intuitively?

- when S, then A
- when $\neg S$, then B

Ambiguities (Example 3, Scenario 2)

Halpern (2016b)

> *"But now consider a slightly different story. This time, we view B as the switch, rather than S. If $B = 1$, then $C = 1$ if either $A = 1$ or $S = 1$; if $B = 0$, then $C = 1$ only if $A = 1$ and $S = 0$."*

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$$C := (B \land (A \lor S)) \lor (\neg B \land (A \land \neg S))$$

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$$C := (B \wedge (A \vee S)) \vee (\neg B \wedge (A \wedge \neg S))$$

What is the actual cause of C, intuitively?

- when B, then A or S or both
- when $\neg B$, then A and $\neg S$

Structural equation models are ambiguous

- It must be the case that some information of these informal scenarios is not expressed by the structural equation model.
- This information does not affect the possible causal worlds.
- This information affects the answer to actual causation problems!

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- This information does not affect the possible causal worlds.
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What kind of information is that? Let's go back to the example.

The extra information

> *"There are four endogenous binary variables, A, B, C, and S, taking values 1 (on) and 0 (off). Intuitively, A and B are supposed to be alternative causes of C, and S acts as a switch. If S = 0, the causal route from A to C is active and that from B to C is dead; . . . "*

The extra information:

- separate causal mechanisms
- causes versus switches for causal mechanisms
- causal processes
- causal mechanisms can be alive or dead

dead $\sim$preempted

Solutions for the ambiguity

- Halpern's solution is a KR methodology :

  > *"what turns out to arguable be the best way to do the disambiguation is to add [. . .] extra variables, which [. . .] capture the* **mechanism of causality***".*
  >
  > *"But all this talk of mechanisms [. . .] suggests that the mechanism should be part of the model".*

- The approach of our paper:
  - Develop a formal language in which the missing information can be expressed.
  - Definitions of actual causation that exploit the extra information.
  - A formalization of the causal *process*
  - No counterfactual definitions (white-box system!)
  - Main goal: a framework to study various definitions of AC in

The idea

- We see separate causal mechanisms
- Some sets of conditions trigger the causal mechanism
- Other conditions could preempt the causal mechanism if not true; they enable/disable the mechanism.

Information about this strongly influences our idea of actual causation.

Syntax: Causal theories

Definition

A causal theory is a a set of causal mechanisms.

Definition

A causal mechanism, or causal law, is an expression of the form

$$A \leftarrow T \,||\, P$$

where A is a literal, T and S sequences of literals

- A literal of T is called a triggering condition of the causal mechanism.
- A literal of P is called an enabling condition of the causal mechanism.

Example 1

- Scenario 1:

$$\begin{aligned} Dead &\leftarrow Arsenic \\ Dead &\leftarrow Strychnine. \end{aligned}$$

- Scenario 2:

$$\begin{aligned} Dead &\leftarrow Arsenic \\ Dead &\leftarrow Strychnine || \neg Arsenic. \end{aligned}$$

Example 3

- Scenario 1:

$$\left\{\begin{array}{l} C \leftarrow A \,||\, \neg S \\ C \leftarrow B \,||\, S \end{array}\right\}$$

- Scenario 2:

$$\left\{\begin{array}{l} C \leftarrow A \,||\, B \\ C \leftarrow S \,||\, B \\ C \leftarrow A, S \,||\, \neg B \end{array}\right\}$$

- We made the information explicit that was available in Halperns informal domain description.

Semantics: possible causal processes

- A possible causal world semantics is not refined enough.
- The formal semantics specifies, for a causal theory Δ:
    - the possible causal processes of Δ
    - the possible causal world that each process leads to.
- How to formalize the causal process?
    - a causal process $\sim$ a dependency graph of the true literals, where edges labeled with:
        1. mechanisms that fire,
        2. role of the literal in the mechanism

Another example: double preemption

Hall (2004)

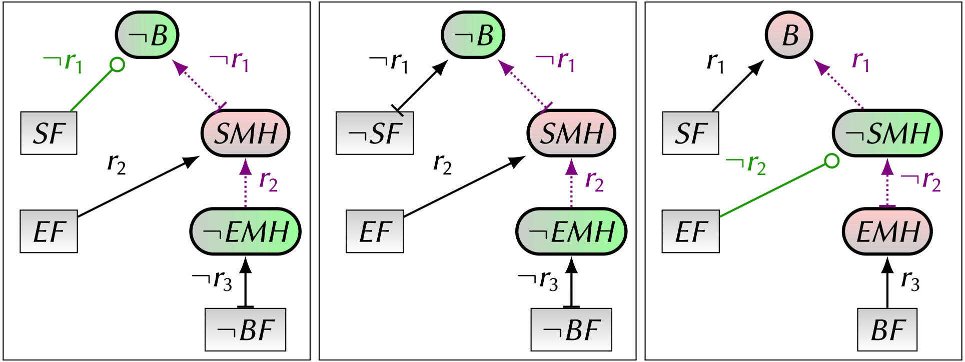
> *Suzy fires a missile (SuzyF) to bomb a target (B); Enemy fires a missile (EnemyF) to hit Suzy's missile (SuzyMH) and Billy fires a missile (BillyF) to hit Enemy's missile (EnemyMH).*

Theory:

$$\left\{ \begin{array}{l} B \leftarrow SuzyF \,||\, \neg SuzyMH \\ SuzyMH \leftarrow EnemyF \,||\, \neg EnemyMH \\ EnemyMH \leftarrow BillyF \,|| \end{array} \right\}$$

Another example: double preemption

$$\left\{ \begin{array}{l} B \leftarrow SuzyF \,||\, \neg SuzyMH \\ SuzyMH \leftarrow EnemyF \,||\, \neg EnemyMH \\ EnemyMH \leftarrow BillyF \,||\, \end{array} \right\}$$



Derived concepts and properties

Derived concepts:

- An actual possible causal process induces a unique possible causal world
  - The possible causal process semantics is more refined than the possible world semantics.
- In a possible world, a causal mechanism can be:
  - firing
  - triggered but preempted
  - non-triggered

Derived concepts and properties

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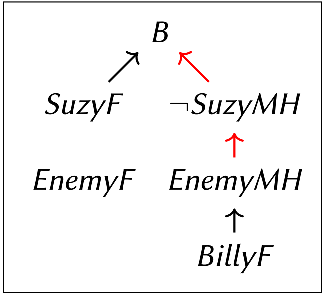
  - non-triggered

Some derived properties:

- All processes in the same exogeneous state cause the same possible world (confluence property)
- The possible causal worlds of Δ are the causal worlds of the structural equation model $\mathit{Completion}(\Delta)$

Definitions of actual causation

The possible causal process is a detailed explanation of the world.



B

$SuzyF$ $\neg SuzyMH$

$EnemyF$ $EnemyMH$

$BillyF$

- x is an influence of y in possible causal process $\mathcal{P}$
- x is an actual P-cause of y
- x is an actual DP-cause of y
- …

Example

Suzy and Billy both pick up rocks and throw them at a bottle....

- In this domain: many variations
- Common causal information:

$$\begin{aligned} \mathit{Shatter} &\leftarrow \mathit{SuzyThrows} \,|| \\ \mathit{Shatter} &\leftarrow \mathit{BillyThrows} \,|| \end{aligned}$$

- other information (who throws, who hits first, ...) is information about the actual causal process (not about the causal domain)

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Conclusions

- A study of several sorts of knowledge that are important for actual causation but are not or not well expressed in many causal languages.
- Logic equipped with a possible causal process semantics.
- Some fundamental aspects of causation: the confluence of causal processes and, paradoxically, a theorem explaining why many useful causation problems can be solved without modelling mechanisms and processes.
- A rich and flexible framework for defining several notions of actual causation.

Future work

- Relation with counterfactual definitions?
- Extending the logic: predicate logic, cyclic causal theories, . . .

Implementation on-line

`http://adams.cs.kuleuven.be/idp/server.html?chapter=intro/11-AC`

- An on-line implementation of many of the examples in the paper
- Using the knowledge base system IDP