On the Syntax and Semantics of Effect Axioms

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Reasoning about Action

- Used mainly in planning and projection.
  - Planning: Computing a sequence of actions that would effect a desired goal state.
  - Projection: Predicting states of the environment as a result of the execution of a sequence of actions—a narrative.

- Motivated foundational research in logic-based AI.
The Yale Shooting Scenario

Effect Axioms.
- \( \text{Occurs}(load, t) \supset \text{Loaded}(t + 1) \)
- \( \text{Loaded}(t) \land \text{Occurs}(\text{shoot}, t) \supset \neg \text{Alive}(t + 1) \)

Initial Situation.
- \( \neg \text{Loaded}(T_0) \)
- \( \text{Alive}(T_0) \)

Narrative.
- \( \text{Occurs}(load, T_0) \)
- \( \text{Occurs}(\text{sneeze}, T_1) \)
- \( \text{Occurs}(\text{shoot}, T_2) \)
Modes of Reasoning about Action

We shall distinguish two modes of reasoning:

Mode 1: Armchair reasoning.
- An agent is reasoning but *not acting*.
- Given a narrative of actions and an initial state, what are the ramifications?

Mode 2: Practical reasoning.
- The agent is acting.
- It needs to reason about its actions as they unfold in time.
Why Mode-2 Reasoning?

- Execution monitoring and replanning.
- Reasoning about what it has done.
  - To figure out ramifications.
  - To report on what it did (possibly in natural language).
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Effect Axioms

- They capture the causal laws of the represented domain.
- They drive all reasoning in an action theory.
- But . . .

Current treatments of effect axioms are so deeply entrenched in the Mode-1 paradigm that their syntax, semantics, and ontological commitments are not suitable for Mode-2 reasoning.
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Current treatments of effect axioms are so deeply entrenched in the Mode-1 paradigm that their syntax, semantics, and ontological commitments are not suitable for Mode-2 reasoning.
Effect axioms are only useful if we know which actions took place.
When used for Mode-2 reasoning, no narrative of actions is available.

In general, the agent needs to reason in order to figure out what actions it performed.

In the absence of a narrative, effect axioms are almost useless, and no inferences are possible.
Why are current treatments of effect axioms inadequate?
Can we specify action theories that are adequate for Mode-2 reasoning?

*It turns out that, by appropriately enriching the ontology of action theories, the resulting effect axioms will be suitable for both Mode-1 and Mode-2 reasoning.*
Outline

1. Effect Axioms
2. The Event Categorization Problem
3. Two Important Distinctions
4. A Unified Framework
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A generic effect axiom has the following structure.

\[[Q_i \land Q] \supset R(\eta_i, a)\]

- \(a\) is an action term.
- \(\eta_i\) denotes an effect of (the denotation of) \(a\).
- \(R(\eta_i, a)\) is a formula involving \(a\) and \(\eta_i\).
Causality

\[ [Q_i \land Q] \supset R(\eta_i, a) \]

- \( R \) may or may not explicitly allude to an element of causality.

**Example**

**Reiter:** \( \text{Loaded}(s) \supset \neg \text{Alive}(do(\text{Shoot}, s)) \)
- No mention of causality, only implication.

**Shanahan:** \( \text{HoldsIn}(\text{Loaded}, s) \supset \text{Terminates}(\text{Shoot}, \text{Alive}, s) \)
- Appeal to causality in the informal semantics of “Terminates” (and “Initiates”).
Qualification

\[ [Q_i \land Q] \supset R(\eta_i, a) \]

- Both \( Q_i \) and \( Q \) qualify the effect axiom but, given the subscript, \( Q_i \) somehow depends on \( \eta_i \) and \( Q \) depends only on \( a \).
- Roughly
  - \( Q \) is a conjunction of executability conditions, required for \( a \) to be executable.
  - \( Q_i \) is a conjunction of effectiveness conditions, required for \( a \) to yield the particular effect \( \eta_i \).

This distinction does not seem to get the attention it deserves in many theories of action.
Qualification: Example 1

\[ [Q_i \land Q] \supset R(\eta_i, a) \]

**Ginsberg and Smith:** \( C(\text{shoot}) = \{\neg\text{Alive}\} \)
- All qualifications are decoupled from effect axioms.
- Enumerated as part of the action description.

*Ginsberg and Smith cannot specify that a loaded gun is needed for the shooting to be lethal, without requiring a loaded gun for the shooting to be possible in the first place.*
Qualification: Example 2

\[
[Q_i \land Q] \supset R(\eta_i, a)
\]

Shanahan:
HoldsIn(HaveGun, s) \land HoldsIn(Loaded, s) \supset Terminates(Shoot, Alive, s)

- Both types of condition appear undistinguished in effect axioms.
- Having a gun and the gun’s being loaded would appear undistinguished in an effect axiom relating shooting to death.

Now, whereas the non-lethal shooting of an unloaded gun is a successful shooting, no action qualifies as a shooting in the absence of a gun.
Some authors explicitly make the distinction between executability and effectiveness conditions (Reiter 01, Giunchiglia et al. 04).

- They provide separate “precondition axioms” specifying executability conditions.
- Effectiveness conditions are conjoined in the antecedent of effect axioms.

However, it seems that the distinction between what should go into the effect axioms and what should be separately asserted is, to a big extent, arbitrary.

*If they do give definitions of qualification, authors typically give vague definitions under which several fine-grained notions are conflated.*
Qualification: Example 3

Reiter 93:

1. Dropping a course results in un-enrollment only if the student is registered in the course.
   - Executability condition.

2. Registering in a course effects registration only if the student have passed all pre-requisites.
   - Normative condition.

3. Changing a grade results in the new grade being $g$ only if $g$ is different from the current grade.
   - Not executability, normative, or effectiveness.

The only problem is that we cannot categorize the action as a change unless the new grade is different from the old one.
The conflation of different types of qualification is partly due to conflating
1. physical actions and
2. their categories (or descriptions).

This is fine for Mode-1 reasoners.

Mode-2 reasoners are at stake: they have to face the event categorization problem.
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Common view in linguistics and philosophy:

- There is a striking similarity between the ways we conceive of time and those in which we conceive of space

- Objects : Matter ≡ Events : States.

- The distinction is topological.
  - Objects are bounded quantities of matter.
  - Events are bounded stretches of state.
The Event Categorization Problem

Events and States

Example

1. I was crossing the street.
2. I crossed the street.

(1) reports the obtaining of a state.
   - As far as we can tell, the speaker might still be crossing the street

(2) reports the occurrence of an event.
   - Event-sentences always imply that the reported situation has come to an end.
Mode-1 and Mode-2, again

- Given a linguistic narrative, the space-time analogy is almost perfect.
- The analogy fails in the way we actually experience time and space.
  - We typically encounter objects, not matter.
  - We only experience states, never events.

No sooner have we reached the end of a situation, than its beginning has already moved into the past, beyond the reach of our conscious experience. Whatever is “now” the case is a state, never an event, for an event has its boundary as an essential part and, thus, can only exist in retrospect, when it has reached an end.
Event Categorization

- If experience consists of only a cascade of states, where do events come from?
- Logically, we must infer event occurrences from patterns of states.
- If some state starts to hold, holds for a while, and then ceases, then we infer the occurrence of an event.
- However, we also need to infer a categorization of this event.
- Until we do so, effect axioms are almost useless.
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For the agent to categorize an action as \( c \), it has to check for all, and only, necessary effects of \( c \).

We can identify necessary effects with effects that are not qualified.

*But now we have to be careful with the different types of qualification.*
Qualification, again

1. Dropping a course results in un-enrollment only if the student is registered in the course.
   - But isn’t un-enrollment a necessary effect of dropping?

2. Registering in a course effects registration only if the student have passed all pre-requisites.
   - Could there be a registering that does not effect registration?

3. Changing a grade to \( g \) results in the new grade being \( g \) only if \( g \) is different from the current grade.
   - Once you’ve changed a grade to \( g \), then the current grade’s being \( g \) is an unconditional, necessary effect.

*In building action theories, we should make sure that effect axioms are not unnecessarily qualified.*
Telic and Atelic Acts

Example

1. I ran.
2. I ran to the store.
3. I ran toward the store.
4. I ran past the store.

- For the atelic (1), only need to have been running for a while.
- For the telic (2),
  1. need to have run,
  2. the running has to have stopped at the store, and
  3. the running has to have caused the agent to be at the store.
Two Important Distinctions

Necessary Initial Conditions

- Telic acts effect a transition from a state $s_i$ to a state $s_t$.
- $s_i$ holds at the onset of the act.
- $s_t$ is caused by the act.
- Typically, $s_i$ and $s_t$ are contradictory.
- Necessarily, $s_t$ does not hold throughout the execution of the act.

For every act category $c$, $\text{NE}(c)$ is the set of necessary effects and $\text{NI}(c)$ is the set of necessary initial conditions.
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Ontology

- Time intervals.
- Time instants.
- States.
- Event tokens.
- Event categories.
  - Instantaneous.
  - Atelic.
  - Telic.
Mappings

- $\uparrow: [\uparrow s]$ is the event category of onsets of state $[s]$.
- $\downarrow: [s \downarrow]$ is the event category of cessations of state $[s]$.
- $\neg:\ [\neg s]$ is the unique state that holds at every instant at which $[s]$ does not hold.
- Prog: $[\text{Prog}(c)]$ is the unique state that holds whenever event category $[c]$ is in progress.
- Clos: $[\text{Clos}(s, t)]$ is the event token of state $[s]$’s maximally holding throughout time $[t]$. 
$t_j$ is an interval; $i$ is an instant; $s$ is a state.

- $t_1 \supset t_2 \overset{\text{def}}{=} t_1 \prec t_2 \land \neg \exists t_3 \left[ t_1 \prec t_3 \land t_3 \prec t_2 \right]$
- $\text{Holds}(s, t) \overset{\text{def}}{=} \forall i \left[ \text{Within}(i, t) \supset \text{HoldsAt}(s, i) \right]$
- $\text{Mholds}(s, t_1) \overset{\text{def}}{=} \text{Holds}(s, t_1) \land \neg \exists t_2 \left[ \text{Holds}(s, t_2) \land t_1 \supset t_2 \right]$
Two Basic Axioms

**AMC.** \( \text{Occurs}(\text{Clos}(s, t), t') \equiv (t' = t) \land \text{MHold}(s, t) \)

**AP.** \[ \text{Occurs}(e, t) \land \text{Cat}(e, c) \] \( \supset \) \( \text{MHold}(\text{Prog}(c), t) \)
Occurrence Conditions

\[ \exists e [\text{Occurs}(e, t) \land \text{Cat}(e, c)] \equiv \phi \]

Consider the form of \( \phi \) for

1. Instantaneous events.
2. Atelic events.
3. Telic events.
Instantaneous Events

**AO.** \( \exists e [\text{Occurs}(e, i) \land \text{Cat}(e, \uparrow s)] \equiv \exists t_1, t_2 [\text{Holds}(\neg s, t_1) \land \text{Holds}(s, t_2) \land \text{Ends}(i, t_1) \land \text{Begins}(i, t_2)] \)

**AC.** \( \exists e [\text{Occurs}(e, i) \land \text{Cat}(e, s \downarrow)] \equiv \exists t_1, t_2 [\text{Holds}(s, t_1) \land \text{Holds}(\neg s, t_2) \land \text{Ends}(i, t_1) \land \text{Begins}(i, t_2)] \)
Atelic Events

- We have the following general condition.
  \[ \text{AA. } \text{Cat}(\text{Clos}(\text{Prog}(c), t), c) \]

- We can prove that
  \[ \text{TA. } \exists e [\text{Occurs}(e, t) \land \text{Cat}(e, c)] \equiv \text{MHold}(\text{Prog}(c), t) \]
Telic Events

\[
\text{AT. } \exists e [\text{Occurs}(e, t_1) \land \text{Cat}(e, c)] \equiv \\
[\text{MHold}(\text{Prog}(c), t_1) \land \bigwedge_{s \in \text{NE}(c)} \text{Holds}(\neg s, t_1) \land \\
\bigwedge_{s \in \text{NI}(c)} \exists t_2 [t_2 \supset t_1 \land \text{Holds}(s, t_2)] \land \\
\bigwedge_{s \in \text{NE}(c)} \exists t_3 [t_1 \supset t_3 \land \text{Holds}(s, t_3) \land \text{Caused}(\text{Clos}(\text{Prog}(c), t_1), \text{Clos}(s, t_3))]]
\]

- Note that standard unqualified effect axioms are derivable from AT.
Changing Grades

- $c =$ change of grade to $g$.
- $\mathcal{NE}(c) = \{ \text{grade is } g \}$
- $\mathcal{NI}(c) = \{ \text{grade is not } g \}$

$$\exists e [\text{Occurs}(e, t_1) \land \text{Cat}(e, \text{Change}(\text{grade}(a), g)) ] \equiv$$
$$[\text{M Holds}(\text{Prog}((\text{Change}(\text{grade}(a), g)), t_1)) \land \text{Holds}(\lnot(\text{grade}(a) = g), t_1) \land$$
$$\exists t_2[t_2 \succ t_1 \land \text{Holds}(\lnot(\text{grade}(a) = g), t_2)] \land$$
$$\exists t_3[t_1 \succ t_3 \land \text{Holds}(\text{grade}(a) = g, t_1), t_3) \land$$
$$\text{Caused}(\text{Clos}(\text{Prog}(c), t_1), \text{Clos}(\text{grade}(a) = g, t_1), t_3))]$$
The syntax and semantics of effect axioms have been largely influenced by armchair reasoning about action. This resulted in missing important distinctions:
- Types of qualification.
- Actions and their categories.

Such theories are not suitable for an agent facing the event categorization problem.

A rich ontology and a distinction between necessary and contingent effects of actions are needed.

The presented framework is adequate for both armchair and practical reasoning modes.
Recommendations for Action Theories

- Different types of qualification should be clearly distinguished.
- Normative and executability conditions should be separated from effect axioms, expressed elsewhere with special syntax.
- The theory should clearly distinguish telic and atelic act categories.
- Necessary initial conditions and necessary effects of telic acts should only occur on the right-hand side of occurrence conditions.