12.3 EVENTS

In Section 10.4.2, we showed how situation calculus represents actions and their effects. Situation calculus is limited in its applicability: it was designed to describe a world in which actions are discrete, instantaneous, and happen one at a time. Consider a continuous action, such as filling a bathtub. Situation calculus can say that the tub is empty before the action and full when the action is done, but it can’t talk about what happens during the action. It also can’t describe two actions happening at the same time—such as brushing one’s teeth while waiting for the tub to fill. To handle such cases we introduce an alternative formalism known as event calculus, which is based on points of time rather than on situations.

Event calculus reifies fluents and events. The fluent $\text{At(Shankar, Berkeley)}$ is an object that refers to the fact of Shankar being in Berkeley, but does not by itself say anything about whether it is true. To assert that a fluent is actually true at some point in time we use the predicate $\text{T}$, as in $\text{T(At(Shankar, Berkeley), t)}$.

Events are described as instances of event categories. The event $E_t$ of Shankar flying from San Francisco to Washington, D.C. is described as $\text{Et E Flying(E1, Shankar) A Origin(Ei, SF) A Destination(E1, DC)}$.

If this is too verbose, we can define an alternative three-argument version of the category of flying events and say $\text{Et E Flying(Shankar, SF, DC)}$.

We then use $\text{Happens(E1, i)}$ to say that the event $E_1$ took place over the time interval $i$, and we say the same thing in functional form with $\text{Extent (E1)} = i$. We represent time intervals by a (start, end) pair of times; that is, $i = \langle t_1, t_2 \rangle$ is the time interval that starts at $t_1$ and ends at $t_2$. The complete set of predicates for one version of the event calculus is

- $\text{T(f, t)}$: Fluent $f$ is true at time $t$
- $\text{Happens(e, i)}$: Event $e$ happens over the time interval $i$
- $\text{Initiates(e, f, t)}$: Event $e$ causes fluent $f$ to start to hold at time $t$
- $\text{Terminates(e, f, t)}$: Event $e$ causes fluent $f$ to cease to hold at time $t$
- $\text{Clipped(f, i)}$: Fluent $f$ ceases to be true at some point during time interval $i$
- $\text{Restored(f, i)}$: Fluent $f$ becomes true sometime during time interval $i$

We assume a distinguished event, $\text{Start}$, that describes the initial state by saying which fluents are initiated or terminated at the start time. We define $\text{T}$ by saying that a fluent holds at a point in time if the fluent was initiated by an event at some time in the past and was not made false (clipped) by an intervening event. A fluent does not hold if it was terminated by an event and

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3 The terms 'event' and 'action' may be used interchangeably. Informally, 'action' connotes an agent while 'event' connotes the possibility of agentless actions.

Some versions of event calculus do not distinguish event categories from instances of the categories.
not made true (restored) by another event. Formally, the axioms are:

\[
\text{Happens}(e, (t_1, t_2)) \land \text{Initiate*}(f, t_1) \land T(f, t) \\
\text{Happens}(e, (t_1, t_2)) \land \text{Terminates}(e, f, t) \land \neg \text{Restored}(f, (t_i, t)) \land t_i < t
\]

where \text{Lipped} and \text{Restored} are defined by

\[
\text{Clipped}(f, t) \iff \exists e, t, t_1 \text{Happens*}(e, (t, t_1)) \land t < t_1 \land \text{Terminates}(e, f, t) \\
\text{Restored}(f, t) \iff \exists e, t, t_1 \text{Happens*}(e, (t, t_1)) \land t < t_1 \land \text{Initiate*}(f, t)
\]

It is convenient to extend \( T \) to work over intervals as well as time points; a fluent holds over an interval if it holds on every point within the interval:

\[
T(f, (t_1, t_2)) \iff (t_1 < t < t_2) \land T(f, t)
\]

Fluents and actions are defined with domain-specific axioms that are similar to successor-state axioms. For example, we can say that the only way a wumpus-world agent gets an arrow is at the start, and the only way to use up an arrow is to shoot it

\[
\begin{align*}
\text{Initiates}(e, \text{HaveArrow}(a), t) & \iff e = \text{Start} \\
\text{Terminates}(e, \text{HaveArrow}(a), t) & \iff e \in \text{Shootings}(a)
\end{align*}
\]

By reifying events we make it possible to add any amount of arbitrary information about them. For example, we can say that Shankar’s flight was bumpy with \( \text{Bumpy}(E_1) \). In an ontology where events are \( n\)-ary predicates, there would be no way to add extra information like this; moving to an \( n+1\)-ary predicate isn’t a scalable solution.

We can extend event calculus to make it possible to represent simultaneous events (such as two people being necessary to ride a seesaw), exogenous events (such as the wind blowing and changing the location of an object), continuous events (such as the level of water in the bathtub continuously rising) and other complications.

### 12.3.1 Processes

The events we have seen so far are what we call discrete events— they have a definite structure. Shankar’s trip has a beginning, middle, and end. If interrupted halfway, the event would be something different—it would not be a trip from San Francisco to Washington, but instead a trip from San Francisco to somewhere over Kansas. On the other hand, the category of events denoted by \( \text{Flyings} \) has a different quality. If we take a small interval of Shankar’s flight, say, the third 20-minute segment (while he waits anxiously for a bag of peanuts), that event is still a member of \( \text{Flyings} \). In fact, this is true for any subinterval.

Categories of events with this property are called process categories or \textit{liquid event} categories. Any process \( e \) that happens over an interval also happens over any subinterval:

\[
(e \in \text{Processes}) A \text{Happens}(e, (t_1, t_2)) \land (t_1 < t < t_2) \land \text{Happens}(e, (t', t_2))
\]

The distinction between liquid and nonliquid events is exactly analogous to the difference between substances, or \textit{stuff}, and individual objects, or \textit{things}. In fact, some have called liquid events \textit{temporal substances}, whereas substances like butter are \textit{spatial substances}. 

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**DISCRETE EVENTS**

**PROCESS**

**LIQUID EVENT**

**SUBSTANCE**

**SPATIAL SUBSTANCE**