ELECTRONIC NEWSLETTER ON
REASONING ABOUT ACTIONS AND CHANGE

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Today

Today's Newsletter contains a question by Murray Shanahan to the article by Marc Denecker, Daniele Theseider Dupre, and Kristof Van Belleghem that is under discussion for the ETAI. We also have a summary of that article - a specification of its contents which is longer and more concrete than an abstract, and which we encourage all ETAI authors to submit in addition to an article itself. The summary makes it easier for everyone to get a quick hold of the contents of the paper.

The discussion about ontologies for time was very lively in April and May, but by the end of May it seemed that several of the contributions must be due to some technical misunderstanding. I therefore asked the participants at that time to take a "timeout" and discuss the matter between themselves, before coming back to the Newsletter audience. Now (and after some editorial delays due to the season) we can present the bottom line: it turns out that Sergio Brandano had defined relations on intervals so that not only

$[a, b] < [c, d]$ iff $b < c$

and

$[a, b] \leq [c, d]$ iff $b \leq c$

but also

$[a, b] = [c, d]$ iff $b = c$

which is where the confusion started.

Debate contributions that are due to this misunderstanding will be edited separately. Today's Newsletter contains two contributions (or parts of contributions, actually) which were made already at the end of May, but which are unrelated to the said misunderstanding. Instead, they are answers to earlier questions by the present editor as to what is lost if one only uses "standard" metric time, for example the set of real numbers without the "punctuation" mentioned by Pat Hayes. With this, it will hopefully be possible to return this debate to its proper topics.

ETAI Publications

Received research articles

The following is a summary of an article that has previously been received by the present ETAI area.

An Inductive Definition Approach to Ramifications

by **Marc Denecker, Daniele Theseider Dupré, and Kristof Van Belleghem**

Summary: This paper describes a new approach to the ramification problem. The approach consists of several contributions.

First of all we show that the standard view on causal laws as rules serving to restore the integrity of state constraints is too restrictive. We argue that causal laws essentially represent the propagation of physical or logical forces through a dynamic system, and that state constraints may be a by-product of this propagation process but that this is not necessarily the case. Therefore we introduce causal laws as pure effect propagation rules independent of state constraints, and define a transition function only dependent on the causal rules which maps each state and set of actions to a resulting state.

Second, we argue that in order to obtain a natural and modular representation of the effect propagation process, the language of causal rules needs to allow for recursion to model mutually dependent effects, as well as for negation to model effects which propagate in the *absence* of other effects. To define a semantics for complex effect theories involving both negative and cyclic dependencies between effects, we observe that a fundamental property of the process of effect propagation is that it is *constructive*: effects do not spontaneously appear without an external cause; each effect must be caused by a preceding effect and in practice effects are generated in a bottom-up way. To adequately model this constructive nature of physical change propagation, we base the semantics of the formalism on the principle of inductive definition, the main mathematical constructive principle.

We use a generalised inductive definition principle, which in fact generalises several different approaches. For theories without recursion, the semantics we propose coincides with completion (and can as such be seen as a generalisation of explanation closure approaches). For theories without negation, the semantics coincides with positive inductive definition semantics and standard circumscription (which has also received a lot of attention in research on the frame problem). For stratified theories the semantics coincides with iterated inductive definitions and with the perfect model semantics for stratified logic programs. In the most general case the proposed operator used in the fixpoint calculation coincides with the well-founded operator in logic programming.

The proposed semantics allows to deal with any effect theories without syntactic restrictions on cycles or negations. As a consequence, syntactically correct effect theories exist which do not have a constructively well-defined model. In particular this is the case for effect theories containing actual cycles over negation, e.g. when the existence of each of two effects depends on the other effect's absence. The physical systems corresponding to such effect theories are rare, and those that exist (those deliberately constructed to yield such an effect theory) exhibit unstable behaviour. But the distinction between good and bad effect theories can not be made based on syntactical properties. Our semantics is such that it detects and marks bad effect theories while it assigns a unique transition function to good, constructive, effect theories, including some that appear syntactically problematic.

A third contribution is the introduction of so-called complex effect rules which provide a higher-level description of effect propagations. These complex effect rules allow to state that it is the change in truth value of a

complex fluent formula, rather than the change of a single fluent, which triggers certain effect propagations. Complex effect rules map to sets of low-level definition rules. We have observed that one form of complex effect rule is sufficiently expressive to model all kinds of temporal reasoning examples known to us, which also suggests that the corresponding low-level rules only occur in particular combinations in practice. The high-level effect rules offer a much more natural and compact way of describing ramifications than the low-level rules. In particular they prove to be very effective for modeling cumulative or canceling effects of simultaneous actions.

An essential property of the semantics, which distinguishes it from several other approaches, is that it is deterministic: for a given effect theory, any combination of a state and set of actions yields a unique set of causations and hence a unique resulting state (sometimes an inconsistent one, in which case the set of actions is not allowed in the given starting state). In our view nondeterminism should be explicitly represented if it is intended, hence we do not allow nondeterminism to arise from special combinations of otherwise deterministic rules. We do describe an extension of effect rules which allows for a limited form of nondeterminism, in that the rules can state that some effects are allowed, but not forced, to occur. This approach has been further extended to more expressive nondeterministic rules, but this issue is beyond the scope of the current paper.

Our approach is presented independent of a specific time structure or formalism, such as Situation Calculus, $\mathcal{A}$ or Event Calculus. We briefly discuss how it can be embedded in these different time structures.

We compare our approach to related work in the literature. In particular we show a correspondence between our nondeterministic effect rules and the causal rules proposed by Thielscher. Differences are, apart from the nondeterministic aspect, especially the different view on delays in effect propagations.

Discussion about received articles

An Inductive Definition Approach to Ramifications

by Marc Denecker, Daniele Theseider Dupré, and Kristof Van Belleghem

Comment from: Murray Shanahan

Marc, Daniele and Kristof,

I haven't read your paper very closely yet. But I'm very interested to understand how your formalism (and indeed any other formalism) works with the circuit example of Figure 1 in your paper.

I can't find anywhere in the paper a precise claim about what your formalisation of this example yields. But presumably, when switch r is closed, switch s opens, $relay1$ is activated, and switch q opens, while $relay2$ remains not activated and switch p remains closed. (By the way it would be nice if the relays were labelled in the diagram.) Is this what your formalisation yields? I guess it is.

To relieve me of the trouble of going through your definitions and proving it myself, can you also tell me what your formalisation yields in the case that switch s is left out altogether. This is obviously more problematic, since the constraints are then contradictory. From r we get $relay2$, which gives $\neg p$, which gives $\neg relay1$ which gives $\neg q$ which gives $\neg relay2$.

Do we get inconsistency according to your formalisation? Or do we get multiple possible outcomes? On page 7, you say that "only theories that do not entail multiple changes of the same fluent at the same time are considered as well-defined". So would this example not be well-defined? Yet this is a realisable circuit. Indeed it's a simplification of the circuit you use as an example. I'm not quite sure what would actually happen - I suppose the relays would get stuck. But something would happen. So maybe inconsistency or no-well-definedness is not what we want in such examples. Or maybe the representation just needs to be a bit more elaborate. What do you think?

Murray

Debates

Ontologies for time

From: Pat Hayes

Erik wants to know why we should bother to consider punctuated times. Well, I guess my first answer would be: ask the people who use the Allen theory. I think it has something to do with natural language understanding. But more concretely, I disagree with Erik's way of thinking. I start with axioms and ask what models they have. Erik starts with models (the real line, for example) and assumes that we somehow have access to the 'standard' ones. But of course we don't: there is no complete computationally enumerable theory of the standard real line. All we have are axiomatic theories.

(In any case, why is the real line 'standard' for time? If anything, quantum physics suggests that time may be more like a kind of everywhere-punctutuated continuum (imagine two copies $R1$, $R2$ of R and order them by: x before y iff $x = y \wedge x \in R1 \wedge y \in R2 \vee x < y$. I find that once one starts playing around with 'nonstandard' models of axioms, the idea that R is 'standard' seems more and more implausible. There are a *lot* of different ways that time could be.)

> The question is whether this standard mathematical view of the line is the most suitable for capturing linguistic intuition or for action reasoning. For example, we want to be able to assert that a light is off before time t and on after time t without having to commit ourselves to its being either on or off **at** that time, but also without sacrificing the assumption that it is always either on or off.

The most natural way of dealing with such a situation, it seems to me, is to admit that one's axioms allow two kinds of models: those where the light is on at time t, and those where it is off. The assumption *that light is either on or off holds in each of the models, but the axioms don't imply one or the other.*

That is one way to think about it. In fact, given any 'punctuated' model, one can always fill it out by putting points at the ends of the intervals and choosing arbitrarily whether or not the light is on (or whatever) at those points. So there are models on the reals even of a theory with punctuated models. But now I return to my earlier point. If we start with the theory and ask, what are its models?, we do get these models on the reals, but we also get rather simpler models which fit the axioms more naturally (and can even be considered to be minimal in a kind of complexity ordering which minimises the size of the domain by cutting out 'surplus' points.) So if you are using this theory and feel uncomfortable with 'nonstandard' models, you can, if you wish, pretend that you are always talking about the real line, though sometimes vaguely (for example, you might not know if an interval is half-open or truly open.) But adopting that stance doesn't magically make the 'nonstandard' models vanish: on the contrary, it is a *theorem* that one can never make the nonstandard models go away. Even set theory has nonstandard models. For myself, I like to know what the nonstandard models are: I find it gives me greater insight into what my axioms really say, as opposed to what I wish they would say.

Erik asks for examples of what can be done with punctuated-time models. I don't know what he means. It is theories that do things, not their models.

Pat Hayes

Here are the axioms of my proposal for a core theory. (The theory can be reformulated without explicitly mentioning intervals, but more awkwardly; and also without explicitly mentioning points, although even more awkwardly and using a little elementary set theory. Its much easier to allow both: but notice that an interval is defined completely by its endpoints.)

1. Points are totally ordered by Before.

2. Every proposition is true over a set of reference intervals.

3. There is a function from pairs of points p, q to the interval $[p, q]$.

4. Intervals Meet only if they share an endpoint, and this point is the unique point When they meet.

5. If p is Before q is Before r, then q is In $[p, r]$

6. $[p, q]$ is a Subinterval of $[r, s]$ if (p = r $\wedge q$ In $[r, s]) \vee (p$ In $[r, s] \wedge q = s) \vee (p$ In $[r, s] \wedge q$ In $[r, s])$

or

6a p $\mathsf{BeforeEq}$ q iff $(p$ Before $q \vee p = q)$

6b $[p, q]$ is a Subinterval of $[r, s]$ if $(r$ Before $p \wedge q$ $\mathsf{BeforeEq}$ $s) \vee (r$ $\mathsf{BeforEq}$ $p \wedge q$ Before $s)$

7. Points have unique Clocktimes.

8. The Clocktime at point q is the Clocktime at p plus the Duration of the interval $[p, q]$.

This theory allows pointlike intervals $[p, p]$ of zero duration, but it doesnt insist that anything be true at such an interval. It also allows 'backward' intervals with negative duration. It allows time to consist of atomic intervals with no subintervals, and it also allows time to be continuous, or any mixture thereof. It allows instantaneous truths and it also allows light-on/off cases with meeting reference intervals. It allows a proposition to be true of an interval but not of its subintervals. All of these variations can be locked in or out by asserting extra conditions using the vocabulary already given.

Now, this theory has models on the reals, naturally. It also has models on the rationals, the integers, and many other more exotic structures, including various 'punctuated' models. (Same theory, different models.) If you relax the total ordering to a partial one it even has models consistent with special relativity. It can be extended to Allenian thinking (by changing 4 and 6 to iff), or it can be extended to Sergioian continuity (the intervals are closed: open intervals are the sets of points In an interval), or to analyse temporal databases (every point has a unique 'next' point with no points between.) Take your pick; but I think you will always find a least this minimal amount of structure in any theory. (Suggested counterexamples welcome!)

From: Jixin Ma

To Erik,

In [ENRAC 98047, 24.5.1998], you put the following questions:

> *What are examples of concrete problems that cannot (conveniently) be represented using a "standard" view of the time axis as e.g. timepoints = the real numbers; time-intervals = sets of points each defined by a lower bound a and an upper bound b.*
>
> *Given that both timepoints and time-intervals are needed to have sufficient expressivity, what is the best way of defining those concepts and their relation?*

The Dividing Instant Problem is a typical problem with the approach of simply constructing time intervals from points (such as reals, rationals or integers), e.g., by means of defining an intervals as a set of points (usually written as a pair of points, denoting the lower bound and the upper bound, i.e., the ending-points) respectively. The DIP is in fact equivalent to the question of whether time intervals include their ending-points or not. If all intervals include their ending-points, then adjacent intervals would have ending-points in common. Hence, if two adjacent intervals correspond to states of truth and falsity of a given fluent, there will be a point at which the fluent is both true and false. Similarly, if all intervals exclude their ending-points, there will be points at which the truth or falsity of some fluents is undefined. Another alternative is to take point-based intervals as semi-open (e.g., all intervals include their left ending-points, and exclude their right ones) so that they may sit conveniently next to one another. However, on the one hand, since this approach insists that every interval contains only a single ending-point, the choice of which ending-point of intervals should be included/excluded seems arbitrary, and hence unjustifiable and artificial. On the other hand, although the approach may offer a solution to some practical questions, there are some other critical questions which remain problematical (examples can be found in AI(42), or Computer Journal 37(210)). The fundamental reason is that in a system where time intervals are all taken as semi-open, it will be difficult to represent time points in an appropriate structure so that they can stand between intervals conveniently.

In your message to Pat appeared in the same issue, you wrote:

> The question is whether this standard mathematical view of the line is the most suitable for capturing linguistic intuition or for action reasoning. For example, we want to be able to assert that a light is off before time t and on after time t without having to commit ourselves to its being either on or off at that time, but also without sacrificing the assumption that it is always either on or off.
>
> *The most natural way of dealing with such a situation, it seems to me, is to admit that one's axioms allow two kinds of models: those where the light is on at time t, and those where it is off. The assumption that light is either on or off holds in each of the models, but the axioms don't imply one or the other.*

Exactly! In fact, as shown in my message (ENRAC 13.3.1998), the approach of treating both intervals and points as primitive on the same footing allows modelling the following *three* cases:

1. the light changes from state "Off" to state "On", and the light is "On" at the switching point t;
2. the light changes from state "Off" to state "On", and the light is "Off" at the switching point t;
3. the light changes from state "Off" to state "On" (but whithout the modelling of the state of the light at the switching point t).

It is important to note that, the treatment here for case 3) is different from the approach which characterises intervals as sets of points. Here, it is not forced to say that there is a point between the Light-Off interval and Light-On interval.

However, it seems that by some careful and proper treatments, we may also reach the same results by defining the concepts of intervals based on points. The key point here is, in addition to the concept of lower and upper bounds for point-based intervals, the concept of left type and right type for intervals needs to be addressed as well. What follows is the skeleton of the structure:

1. P is a partially-ordered set of points;
2. *Type* is a two-member set $\{open, closed\}$;
3. An interval i is defined as a quaternion $seq(p1, p2, l, r)$ such that:
   - $p1 \leq p2$
   - l and r belong to *Type*
   - if $p1 = p2$ then $l = r = closed$

Therefore, if we take point, p, as identical to closed point-like interval (p,p,closed,closed), the set of point can be taken as a subset of the set of intervals.

The relation between intervals, *Meets*, is defined as:
$Meets(seq(p1', p2', l', r'), seq(p1'', p2'', l'', r''))$ iff $p2' = p1'' \wedge \neg(r' = l'')$

It is easy to see that such a Meets relation defined here represents the relationship that an interval is immediately before another interval (no matter wether the set of points is further characterised as dense or discrete), without any other intervals standing between them. All other temporal relations, such as *Before*, *Starts*, *During*, etc., can be derively defined in terms of the *Meets* relation.

Additional issues such as dense/discrete, linear/nonlinear structure, and so on, may be characterised by means of extra axioms.

Also, some extra constraints about the internal structure of intervals may be imposed.

It has been checked that such a point-based time model has the expressive power of that based on both intervals and points as primitive. For instance, it can also express all the above three cases successfully. In fact, it seems that the two are equivelent!

Jixin

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