Preliminary Insights on Temporal Approximation

Aarati Parmar
Formal Reasoning Group
Department of Computer Science
Stanford University
aarati@cs.stanford.edu

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Introduction

- This work defines and formalizes some kinds of *temporal approximations and refinements*.
- *Temporal approximation*: transformation of a theory of action and change to a simpler one, along temporal coordinates.
- *Temporal refinement*: opposite, adds more detail or explanations.
- Robots will need the ability to jump between different levels of temporal reasoning:
  - Both to simplify problems in order to solve them, and
  - Refine them as more information becomes available.
- Four approximations/refinements studied here:
  1. Ramifications as internal events.
  2. Elaboration of a narrative.
  3. Expansion of events.
  4. Increasing predictive capacity of theories.

Preliminaries

- Use situation calculus with sorts $Situations$, $Events$ (includes actions) and $Fluents$.
- Language includes $Result(e, s)$, as well as relation $Occurs(e, s)$ and function $Next(s)$.
- General principle in this paper:
  - We leave out traditional axioms (like induction, arboreal) for now – stay unrooted to usual intended interpretations.
  - Our formalizations are recipes – the language is the ingredient; how we combine the ingredients (axioms and intended interpretations) is up to us!

Preliminaries: More on $Occurs$ and $Next$

- $Occurs(e, s)$ asserts: event e occurs at situation s.
- $Next(s)$: resulting situation of whatever events occur at s
- Example:

$$\begin{gathered} Occurs(fall(domino), s) \implies \neg Upright(domino, Next(s)) \\ \neg Upright(domino, Result(pushover(domino), s)) \end{gathered} \tag{1}$$

- No way to distinguish between actual and hypothetical situations, contrary to presence of $Occurs(e, s)$ – the s in $Occurs(e, s)$ could itself be hypothetical:

$$\begin{gathered} Occurs(book\text{-}ticket(Edmonton), Result(accept(paper), s)) \wedge \\ Occurs(book\text{-}ticket(Las\ Vegas), Result(reject(paper), s)) \end{gathered} \tag{2}$$

Preliminaries: Further Notation

- $\gamma_F^+(e,s)$: conditions for fluent F to hold in $Result(e,s)$, while $\gamma_F^-(e,s)$, $\neg F$.
- $\nu_F^+(s)$ are the conditions for F to hold in s through ramifications or static constraints; $\nu_F^-(s)$, $\neg F(s)$.
- All four are *simple formulae* – only situation variable is the free variable s.
- Consistency assumption [McIlraith, 2000] (Can't have both F and $\neg F$ caused at the same time):

$$\begin{aligned}\neg[(\gamma_F^+(e,s) \vee \nu_F^+(Result(e,s)))\wedge \\ (\gamma_F^-(e,s) \vee \nu_F^-(Result(e,s)))]\end{aligned} \tag{3}$$

- Ignore $Poss(e,s)$, assuming that γs are written to assume inertia when $\neg Poss(e,s)$.
- *sequence of situations*: $s_1,\ldots,s_n = \overline{s}$,
  where $s_{i+1} = Next(s_i) \vee (\exists e)s_{i+1} = Result(e,s)$.
- Order $s < t$ iff there is a sequence of situations $s_1,\ldots,s_n$, $n > 1$ where $s_1 = s$ and $s_n = t$.

1. Ramifications as Internal Events

- [McCarthy, 2002] formalizes static constraints in terms of internal events.
- An imbalance in a static constraint = occurrence of an spontaneous event which resolves the imbalance.
- So for example, static constraint

$$Blocked(vent1, s) \wedge Blocked(vent2, s) \implies Stuffy(s) \tag{4}$$

is transformed to the *event occurrence axiom*

$$[Blocked(vent1, s) \wedge Blocked(vent2, s) \wedge \neg Stuffy(s)] \implies Occurs(Becomes\text{-}Stuffy, s), \tag{5}$$

along with the *event effect axiom*

$$Occurs(Becomes\text{-}Stuffy, s) \implies Stuffy(Next(s)). \tag{6}$$

This surgery on ramifications gives directionality to ramifications *without* using special logic (uses $Next$).

- Depends on a causal reading of implication in static constraints, as noted in [McIlraith, 2000].

1. Ramifications as Internal Events: A Closed-Form Solution

- We borrow [McIlraith, 2000]'s closed-form solution to the frame problem with ramifications. It assumes theories are *solitary stratified* – every static constraint is of the form $\nu_F^+(s) \implies F(s)$ or $\nu_F^- \implies \neg F(s)$, and we can assign numbers to fluents so that those mentioned in the νs are strictly less that that of F.

- But, instead of compiling all effects directly into successor state axioms, we only compile in immediate effects γs. The rest of the ramifications percolate along event occurrence and effect axioms along $Next$ trajectories.

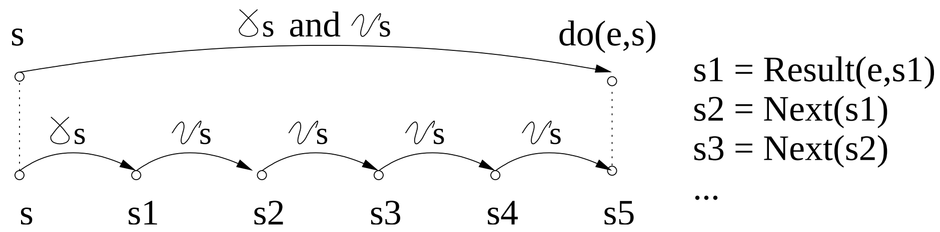

Figure 1: Difference btw [McIlraith, 2000]'s treatment of effects (top) and ours (bottom).

- Not sure if lead to same answers – all we know so far is that percolation does reach quiescence with solitary stratified theories.

2. Elaboration of a Narrative

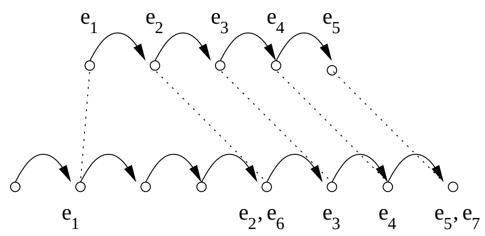

Figure 2: *Dense refinement*: more interleaving and even co-occurring events are added.

- Can add more detail, but should not refute other parts.
- Sequence of situations $\bar{t}$ in T' densely refines $\bar{s}$ in T if one can find a mapping σ from situations in $\bar{s}$ to $\bar{t}$ such that:
  1. $s < s' \implies \sigma(s) < \sigma(s')$
  2. All events mandated by T at s occur in T' in $\sigma(s)$.
  3. If $\sigma(s') = Result(e, \sigma(s))$ in T', then $s' = Result(e, s)$ in T.
  4. The same fluent formulas holding at situations in T hold in the mapped situations at T'.
- Subsequence $\sigma(\bar{s})$ is a *skeleton* in $\bar{t}$ which corresponds to original sequence $\bar{s}$.
- From this primitive relation of dense refinements hopefully we can come up with intuitive temporal relations between theories.

3. Expansion of Events

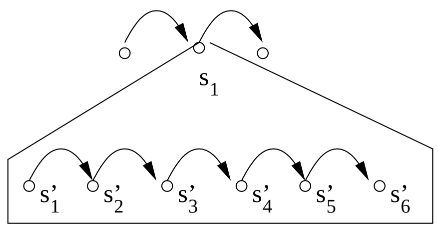

Figure 3: *Expansive refinements*: one situation expanded to reveal a sequence of situations.

- Example: Situation of "buying a box of tissue" can be refined to be the sequence of entering a store, getting tissue, putting it on counter, and paying for it.
- This variability of temporal granularity perhaps one of the biggest features of situations (as opposed to time points), but not exploited.
- Possible formalisms/clues:
  - Study of duality between fluents and events? [Pinto, 1994]?
  - Tense of verbs?
  - *Realizability*: refined sequence of situations *realizes* bigger situation much as a proof realizes truth of formula.
  - Granularity [Hobbs, 1985]: Result of viewing time at a lower granularity (little situations get compressed into one big one.)

4. Increasing the Predictive Capacity of Theories

- Contrast *external events* introduced by $Result$ and *internal events* postulated by $Occurs$:

	External events	Internal events
Event term introduced by:	$Result$	*event occurrence axioms*
Effects described by:	*effect axioms*	*event effect axioms*
To see effects of event:	Must manually query $Result(e, s)$	Just look at $Next(s)$
T explains why they occur?	No	Yes

- Theory where more events are internal is more *predictive*. (Axioms tell you what events $Occur$).

- Can make a theory more predictive (change external to internal events) *simply by adding more event occurrence and effect axioms.*

- These axioms serve to *explain* events, and thus make T more informative.

Conclusions and Discussion

- Some preliminary formalizations of some different temporal approximations.
- Any comments and suggestions appreciated!

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[a] http://www-formal.stanford.edu/jmc/sitcalc/sitcalc.html
[b] http://www.cs.toronto.edu/cogrobo/jpThesis.ps.Z

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[2] http://www.cs.toronto.edu/cogrobo/jpThesis.ps.Z