A Situation-Calculus Semantics for an Expressive Fragment of PDDL

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Outline

1. Introduction
   - Background and Motivation
   - The PDDL Language
   - Logical Foundations

2. Situation-Calculus Semantics for PDDL
   - Simple Actions
   - Durative Actions
   - Other Features

3. Discussion
   - Correctness
   - Conclusion and Future Work
A state-transitional semantics for PDDL exists (Fox & Long 03)

- Meta-theoretic, *e.g.*
  - Invariant conditions protected by dummy actions
  - Conditional effects handled by splitting an action into two

- Complexity (19-page definition)

Goal: A declarative semantics for PDDL

- Based on a well-understood logic
- Analyze planning problems with logical entailments
- Bridge planning and reasoning-about-actions communities
  - *e.g.* Embedding planners in temporal Golog
We cover PDDL 2.1 & 2.2, excluding derived predicates.
The Planning Domain Definition Language

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A running example: The Electro-Car domain

- Predicates: $At(v, l)$, $Engine(v)$, $Power(v)$;
- Functions: $miles(v)$, $velocity(v)$, $distance(l_1, l_2)$.
- Actions
  - $unplug(v)$: simple action that removes power of $v$
  - $drive(v, l_1, l_2)$: durative action with duration $\frac{distance(l_1, l_2)}{velocity(v)}$ and $Power(v)$ as invariant condition. If engine was off before the start of driving, turn it on at start and off again at end.
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$(:action unplug (:parameters ?v - vehicle) (:effect (not (power ?v))))$
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\[(:\text{durative-action} \text{ drive} \quad (:\text{parameters} \ ?v \ - \ \text{vehicle} \ ?l_1 \ \text{location}) \quad (:\text{parameters} \ ?l_1 \ ?l_2 \ - \ \text{location}) \)]
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\[
(:\text{durative-action} \ \text{drive} \\
\text{:duration} \ (= \ ?\text{duration} \ (/ \ \text{distance} \ ?l1 \ ?l2 \ \text{velocity} \ ?v))))
\]
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\((:durative-action drive
  (:condition ... (over all (power ?v)) ...)\)
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\[
(:durative-action drive
 (:effect (when (at start (not (engine ?v))))
 (at start (engine ?v)))))
\]
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The Logic $\mathcal{ES}$

$\mathcal{ES}$ (Lakemeyer & Levesque 04) is a modal logic capturing SitCalc

- $[a] \alpha$: formula $\alpha$ holds after action $a$
- $\square \alpha$: formula $\alpha$ holds after any sequence of actions
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The Basic Action Theory $\Sigma = \Sigma_{pre} \cup \Sigma_{post} \cup \Sigma_0$

- $\Sigma_{pre}$: precondition axiom $\Box Poss(a) \equiv \Pi$,
  e.g. $\Box Poss(a) \equiv a = move(x, y) \land Clear(x) \land Clear(y) \lor a = moveToTable(x) \land Clear(x)$

- $\Sigma_{post}$: successor state axioms $\Box[a] F(\vec{x}) \equiv \Phi_F(\vec{x}, a)$
  e.g. $\Box[a] On(x, y) \equiv a = move(x, y) \lor On(x, y) \land \neg(a = moveToTable(x) \lor \exists z. a = move(x, z))$

- $\Sigma_0$: initial database,
  e.g. $On(x, y) \equiv (x = a \land y = b) \lor (x = b \land y = c)$
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- $\Sigma_{post}$: successor state axioms $\Box[a]F(\vec{x}) \equiv \Phi_F(\vec{x}, a)$
  - e.g. $\Box[a]\text{On}(x, y) \equiv a = \text{move}(x, y) \lor \text{On}(x, y) \land \neg(a = \text{moveToTable}(x) \lor \exists z. a = \text{move}(x, z))$

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The regression operator $\mathcal{R}$ transforms a formula to an equivalent one without $[a]$ operator, e.g. $\Sigma \models [a]\alpha$ iff $\Sigma_0 \models \mathcal{R}[a, \alpha]$
Temporal extension similar to (Pinto & Reiter) in SitCalc

- **Time:**
  - $A(\vec{x})$ is extended to $A(\vec{x}, t)$, with $\text{time}(A(\vec{x}, t)) = t$
  - The start time of current situation: $\square[a](\text{now} = \text{time}(a))$
  - Ensure correct temporal ordering: $\square\text{Poss}(a) \supset \text{now} \leq \text{time}(a)$

- **Durative actions modeled by instantaneous actions + fluents**
  - $\text{start}(\text{walk}(x, y), t), \text{end}(\text{walk}(x, y), t), \text{Performing}(\text{walk}(x, y)), \text{since}(\text{walk}(x, y))$
Simple Actions

Mapping \textit{ADL} problems to BAT in ES follows (Cläßen \textit{et al.} 07)

- Initial Database $\Sigma_0$: Initial world + Typing
- Precondition axiom $\Sigma_{pre}$: Case disjunction over all operators
- Successor state axioms $\Sigma_{post}$
  - For each fluent predicate $F_j(\vec{x}_j)$, extract the positive condition $\gamma^+_F$ and the negative condition $\gamma^-_{F_j}$ from the effect definitions of all actions, and obtain the SSA

$$\Box[a]F_j(\vec{x}_j) \equiv \gamma^+_F \land \vec{n}_j(\vec{x}_j) \lor F_j(\vec{x}_j) \land \neg \gamma^-_{F_j};$$
Simple Actions

Mapping ADL problems to BAT in ES follows (Cläßen et al. 07), (numerical) functional fluents are handled similarly.

- **Initial Database** $\Sigma_0$: Initial world + Typing
- **Precondition axiom** $\Sigma_{pre}$: Case disjunction over all operators
- **Successor state axioms** $\Sigma_{post}$
  - For each fluent predicate $F_j(x_j)$, extract the positive condition $\gamma^+_F$ and the negative condition $\gamma^-_F$ from the effect definitions of all actions, and obtain the SSA
    \[ \square[a]F_j(x_j) \equiv \gamma^{+}_F \land \tau^+_j(x_j) \lor F_j(x_j) \land \neg \gamma^-_F; \]
  - For each fluent function $f_j(x_j)$, extract the update condition $\gamma^{\nu}_{f_j}$ from effect definitions of all actions, and obtain the SSA
    \[ \square[a]f_j(x_j) = y_j \equiv \gamma^{\nu}_{f_j} \land \tau^{\nu}_j(x_j) \lor f_j(x_j) = y_j \land \neg \exists y'. (\gamma^{\nu}_{f_j})^{y_j}_{y'} \]
Durative Actions

For each $\text{PDDL}$ durative action $\tilde{A}(\vec{x})$, map “at start” conditions and effects to $\text{start}(\tilde{A}(\vec{x}), t)$, and “at end” ones to $\text{end}(\tilde{A}(\vec{x}), t)$.

(:durative-action drive
 :parameters (?v - vehicle ?l1 ?l2 - location)
 :duration (= ?duration (/ (distance ?l1 ?l2) (velocity ?v)))
 :precondition (and (at start (at ?v ?l1))
 (over all (power ?v)))
 :effect (and (at start (not (at ?v ?l1)))
 (when (at start (not (engine ?v)))
 (and (at start (engine ?v))
 (at end (not (engine ?v)))))
 (at end (at ?v ?l2))
 (at end (increase (miles ?v) (distance ?l1 ?l2))))

$\text{start}(\text{drive}(v, l_1, l_2), t)$
$\text{end}(\text{drive}(v, l_1, l_2), t)$
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Problems: Duration constraint, invariant condition and inter-temporal conditional effect are ignored.
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Problems: Duration constraint, invariant condition and inter-temporal conditional effect are ignored.
Invariant Condition

\[ drive(v, l_1, l_2) \]

\[ Power(v) \]

\[ unplug(v) \]

\[ Power(v) \]
In invariant Condition

Protect the invariant condition of \( \text{drive}(v, l_1, l_2) \) by not allowing actions that violate it (e.g. \( \text{unplug}(v) \)) to happen.
Invariant Condition

Protect the invariant condition of \( \text{drive}(v, l_1, l_2) \) by not allowing actions that violate it (e.g. \( \text{unplug}(v) \)) to happen.

Formally, assert

\[
\square \text{Poss}(a) \supset [a](\text{Performing}(\text{drive}(v, l_1, l_2)) \supset \text{Power}(v))
\]
Invariant Condition

Protect the invariant condition of $\text{drive}(v, l_1, l_2)$ by not allowing actions that violate it (e.g. $\text{unplug}(v)$) to happen.

Formally, assert

$$\Box \text{Poss}(a) \supset \mathcal{R}[a, \text{Performing}(\text{drive}(v, l_1, l_2)) \supset \text{Power}(v)]$$
Invariant Condition

Protect the invariant condition of \( \text{drive}(v, l_1, l_2) \) by not allowing actions that violate it (e.g. \( \text{unplug}(v) \)) to happen.

Formally, assert

\[
\square \text{Poss}(a) \supset R[a, \text{Performing}(\text{drive}(v, l_1, l_2)) \supset \text{Power}(v)] \iff
\]

\[
[\exists t. a = \text{start}(\text{drive}(v, l_1, l_2), t) \lor \text{Performing}(\text{drive}(v, l_1, l_2)) \land \\
\neg \exists t. a = \text{end}(\text{drive}(v, l_1, l_2), t)] \supset [\text{FALSE} \lor \text{Power}(v) \land \neg \exists t. a = \text{unplug}(v, t)]
\]
Invariant Condition

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Formally, assert

$$\Box \text{Poss}(a) \supset \{$$

$$[\exists t. a = \text{start}(\text{drive}(v, l_1, l_2), t) \lor \text{Performing}(\text{drive}(v, l_1, l_2)) \land$$

$$\neg \exists t. a = \text{end}(\text{drive}(v, l_1, l_2), t)] \supset [\text{FALSE} \lor \text{Power}(v) \land \neg \exists t. a = \text{unplug}(v, t)]$$

$$\}$$
Other Features

- **Concurrency**
  - Interleaved concurrency
    
    \[\text{e.g. } [\text{unplug(car, 5)}][\text{unplug(truck, 5)}] \neg \text{Power(car)}\]

- **Continuous effects**
  - Introduce linear functions to BAT (Grosskreutz & Lakemeyer 00)

- **Timed initial literals**
  - \text{e.g. } (at 2 (engine truck))

  introduce a new and unique action \text{turn\_on\_engine} with 
  \text{Poss(turn\_on\_engine(2)) } \land \text{Obli(turn\_on\_engine(2))}
  and with the single effect to make \text{Engine(truck)} true.

- **Start duration constraint**
  - “Remember” the involved function values at the start event, and assert the constraint at the end.

- **Invariant condition with continuous effect**
  - Force execution of \text{end} action.
Correctness

Theorem

Let $\Sigma$ be the result of applying the above mapping to a PDDL problem with goal formula $\psi$. Let $P$ be a plan with no concurrent mutex actions. Then $P$ is valid according to (Fox & Long 03) iff there is a linearization $\langle r_1, \cdots, r_k \rangle$ of $P$ such that

$$\Sigma \models [r_1] \cdots [r_k] (Executable \land \psi \land \neg \exists a. Performing(a))$$
Conclusion and Future Work

Contribution

- We present a situation-calculus semantics for the temporal fragment of PDDL;
- Theoretical ground for relating PDDL to other situation calculus based formalisms, e.g., Golog;
- Offer an alternative view on temporal planning, (e.g., Cushing et al. (2007) observe that most state-of-the-art planners are temporally simple.)

Ongoing and future work

- Temporally-expressive planner based on the semantics;
- Extend the result to include preferences and constraints on plan trajectory in PDDL 3.0.