Applied Logic I

Reasoning about Action

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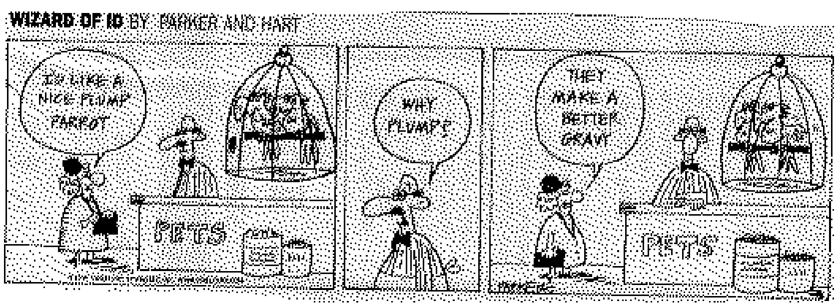
Introduction to Reasoning About Action



Reasoning About Action

- Many of the environments about which we wish to reason are dynamic in nature
- That is, they are constantly changing due to the performing of actions
- For example, consider a robot whose job it is to deliver packages in an office environment
- In this lecture we shall consider some of the issues that arise when representing and reasoning about a changing world
- It turns out that the techniques we have discussed in previous lectures can be used to attack the problems that arise but we do not have the time to investigate these issues in any great depth here

Overview

- Reasoning About Action
  - Situation Calculus
  - States/Situations
  - Domain Constraints
  - Actions
  - The Frame Problem
  - Summary
- Morals
- Where to next?

Reasoning About Action

- One method to reason about action is to simply change the agent's knowledge base
- Erase some sentence(s) that should no longer be true and add sentences that will now be true (i.e., after performing action)
- However, we can only answer questions about the current state
- It will not be possible to reason about past or future states
- On the other hand, if all we want to do is reason about which actions to perform, this may be a viable approach (may return to this later)

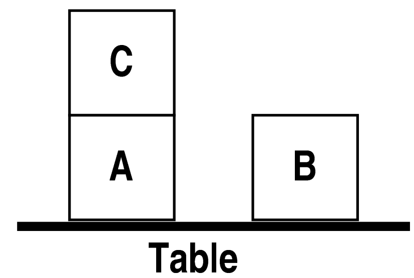
Situation Calculus

- The situation calculus is a way of describing change in first-order predicate calculus
- Situation/State — a snapshot of the world at a particular point in time
- Aspects we need to consider:
  - The state of the world
  - Actions that change state of the world and what changes they effect
  - Constraints on legal scenarios
  - Can you think of anything else?

The Blocks World

We shall consider one of the more famous AI domains — the blocks world

In the blocks world we have blocks that can be placed on the table and can be stacked on each other



State of the World

- State — description of what holds (is true) in the world at a particular point in time
- Situation — state + time (includes history)
- Method 1:

  $on(C, A, S_1)$
  $on(A, Table, S_1)$
  $on(B, Table, S_1)$
  $clear(B, S_1)$
  $clear(C, S_1)$

- Initial situation: $S_0/init$

Note: we reify states (i.e., make them entities in our formalisation)

State of the World

- There are of course other ways to formalise this scenario
- Another common way using the situation calculus is as follows
- Method 2:

  $holds(on(C, A), S_1)$
  $holds(on(A, Table), S_1)$
  $holds(on(B, Table), S_1)$
  $holds(clear(B), S_1)$
  $holds(clear(C), S_1)$

Domain Constraints

- Also known as state constraints
- True at all (legal) states even though they involve state-dependent relations

  x is on the table iff it is not on top of another block

  $\forall x, \forall y, \forall s(on(x, Table, s) \leftrightarrow \neg\exists y(on(x, y, s) \wedge y \neq Table))$

  x is clear iff there is no block on top of it

  $\forall x, \forall s(clear(x, s) \leftrightarrow \neg\exists y\, on(y, x, s))$

  If y is a block and there is another block on it, then y is not clear

  $\forall x, \forall y, \forall s(on(x, y, s) \wedge \neg(y = Table) \rightarrow \neg clear(y, s))$

etc.

Actions

$do(A(\ldots), S)$ — "Do action A in situation S"

- In fact, do is a function returning a situation which is the result of performing (doing) action A in situation S (if that is possible)
- For example, "move block x from y to z" and "clear x"
- We will need to specify what each action does to the world
- Positive effect axiom for *on*

  $\forall x, \forall y, \forall z, \forall s(on(x, y, s) \wedge clear(x, s) \wedge clear(z, s) \wedge (x \neq z) \rightarrow on(x, z, do(move(x, y, z), s)))$
- Negative effect axiom for *on*

  $\forall x, \forall y, \forall z, \forall s(on(x, y, s) \wedge clear(x, s) \wedge clear(z, s) \wedge (x \neq z) \rightarrow \neg on(x, y, do(move(x, y, z), s)))$

Effect Axioms for *clear*

- Positive effect axiom for *clear*

  $\forall x, \forall y, \forall z, \forall s(on(x, y, s) \wedge clear(x, s) \wedge clear(z, s) \wedge (x \neq z) \wedge (y \neq z) \rightarrow clear(y, do(move(x, y, z), s)))$
- Negative effect axiom for *clear*

  $\forall x, \forall y, \forall z, \forall s(on(x, y, s) \wedge clear(x, s) \wedge clear(z, s) \wedge (x \neq z) \wedge (z \neq Table) \rightarrow \neg clear(z, do(move(x, y, z), s)))$
- We need positive and negative effect axioms for every fluent (predicate that can change value)
- How many such axioms do you need to specify?!

The Frame Problem

- Action descriptions are not complete:
  - They describe what changes
  - They do **not** specify what stays the same
- The (famous) Frame Problem:

  The problem of characterising those aspects of the state description that are not changed by an action
- One solution — Frame Axioms

  $(on(x, y, s) \wedge (x \neq u)) \rightarrow on(x, y, do(move(u, v, z), s))$
  $(\neg on(x, y, s) \wedge ((x \neq u) \vee (y \neq z))) \rightarrow \neg on(x, y, do(move(u, v, z), s))$

  $(clear(u, s) \wedge (u \neq z)) \rightarrow clear(u, do(move(x, y, z), s))$
  $(\neg clear(u, s) \wedge (u \neq y)) \rightarrow \neg clear(u, do(move(x, y, z), s))$

Ramification Problem

- What are the ramifications (direct and indirect effects) of performing an action

  $$\neg clear(b, do(move(c, a, b), S_0))$$
- Recent approaches have investigated the use of explicit notions of causality in an attempt to solve this problem efficiently

Qualification Problem

- What qualifications (preconditions) do we require in specifying actions and their effects
- Trying to specify exactly under which conditions an action has a particular effect is very difficult (in principle, the list of preconditions can be vast)

Reasoning with the Situation Calculus

- If we would like to determine a plan to achieve goal $\Gamma(s)$, prove $\exists s \Gamma(s)$
  - **Goal:** $\neg on(B, Table, s)$
  - **Given:**
    $on(B, A, S_0)$
    $on(A, C, S_0)$
    $on(C, Table, S_0)$
    $clear(B, S_0)$
    $clear(Table, S_0)$
    $(on(x, y, s) \wedge clear(x, s) \wedge clear(z, s) \wedge (x \neq z)) \rightarrow on(x, z, do(move(x, y, z), s$
  - (Also require unique names axioms, equality axioms: $(A = A)$, $\neg(A = B)$, etc., etc.)
  - **Obtain:** $s = do(move(B, A, Table), S_0))$

Summary

- Reasoning about actions is a very interesting area of artificial intelligence and often makes use of belief change and nonmonotonic reasoning techniques
- We have seen that a number of challenging problems arise that we must deal with in order to reason effectively
- One of the problems, however, is the possible proliferation of axioms
- The search continues for a concise solution to the frame problem (and associated problems)
- Other formalisms include the event calculus, $\mathcal{A}$ languages, features and fluents, fluent calculus
- Current research: causal approaches, cognitive robotics, planning (an area in its own right)

Some Morals?

- The way you use a logic is important. It can lead to more complex behaviour (for example, AGM belief change, predicate completion, etc.)
- Structure is important (for example, epistemic entrenchment, systems of spheres, etc.).

Where to Next?

- Belief Change

  - Carlos E. Alchourrón, Peter Gärdenfors, and David Makinson. On the logic of theory change: Partial meet contraction and revision functions. *Journal of Symbolic Logic*, 50:510–530, 1985. Original (joint) paper on AGM framework.
  - Peter Gärdenfors and David Makinson. Revisions of knowledge systems using epistemic entrenchment. In *Proceedings of the Second Conference on Theoretical Aspect of Reasoning About Knowledge*, pages 83–96, 1988. Original paper on epistemic entrenchment construction for AGM belief change operators.
  - Peter Gärdenfors. The dynamics of belief systems: Foundations vs. coherence theories. *Revue Internationale de Philosophie*, 44:24–46, 1990. Good brief introduction to some of the main ideas underlying the AGM approach.

  - Peter Gärdenfors. *Belief Revision*. Cambridge University Press, 1992. Edited collection of papers on belief change. Includes a brief summary paper by Gärdenfors on the AGM approach.
  - Peter Gärdenfors and David Makinson. Nonmonotonic inference based on expectations. *Artificial Intelligence*, 65:197–245, 1994. Describes link between AGM and (formal) work on nonmonotonic logics.
  - Peter Gärdenfors and Hans Rott. Belief revision. In Dov M. Gabbay, Christopher J. Hogger, and John A. Robinson, editors, *Handbook of Logic in Artificial Intelligence and Logic Programming Volume IV: Epistemic and Temporal Reasoning*, pages 35–132. Oxford University Press, 1995. More up-to-date summary of AGM approach with an emphasis on belief base approaches.
  - Adam Grove. Two modellings for theory change. *Journal of Philosophical Logic*, 17:157–170, 1988. Original paper on system of spheres construction for AGM belief change operators.
  - Sven Ove Hansson. A textbook of belief dynamics: Theory

  change and database updating. Kluwer, 1999. Destined to become the new reference on AGM-style belief change.
  - Gilbert H. Harman. *Change in View: Principles of Reasoning*. MIT Press, 1986. Philosphical work discussing issues in belief change.
  - Hirofumi Katsuno and Alberto O. Mendelzon. On the difference between updating a knowledge base and revising it. In Peter Gärdenfors, editor, *Belief Revision*, pages 183–203. Cambridge University Press, 1992. A preliminary version of a paper bearing the same title appearing in James Allen, Richard Fikes and Erik Sandewall (editors), *Principles of Knowledge Representation and Reasoning: Proceedings of the Second International Conference*, Morgan Kaufmann, CA, pp. 387-394, 1991. Original paper on belief update.
  - S. Kraus, D. Lehmann, and M. Magidor. Nonmonotonic reasoning, preferential models and cumulative logics. *Artificial intelligence*, 44:167–207, 1990. Formal treatment of nonmonotonic logics. Difficult paper.

- David Makinson. On the status of the postulate of recovery in the logic of theory change. *Journal of Philosophical Logic*, 16:383–394, 1987. Discusses issues surrounding Recovery postulate in AGM contraction operator.
- Wolfgang Spohn. Ordinal conditional functions: A dynamic theory of epistemic states. In William L. Harper and Brian Skryms, editors, *Causation in Decision, Belief Change, and Statistics, II*, pages 105–134. Kluwer Academic Publishers, 1988.

Nonmontonic Reasoning

- Michael R. Genesereth and Nils J. Nilsson, *Logical Foundations of Artificial Intelligence*, Morgan Kaufmann, 1987. Good reference for the use of logic in artificial intelligence. Getting a bit dated though.
- John McCarthy, Circumscription—A Form of Nonmonotonic Reasoning, *Artificial Intelligence*, vol 13, 1980. Classic paper on circumscription.
- John McCarthy, Applications of Circumscription to Formalizing

Common Sense Knowledge, *Artificial Intelligence*, vol 26, 1986.
- David Poole, A Logical framework for Default Reasoning, *Artificial Intelligence*, **36(1):**27–47, 1988.
- Raymond Reiter, A Logic for Default Reasoning, *Artificial Intelligence*, **13(1-2:**81–132, 1980. Classic paper on default reasoning.
- Karl Schlechta, *Nonmonotonic Logics: Basic Concepts, Results, and Techniques*, Springer Verlag, 1997.

Reasoning about Action

- A. Baker, Nonmonotonic Reasoning in the Framework of the Situation Calculus, *Artificial Intelligence*, vol 49, 1991.
- M. Ginsberg and D. Smith, Reasoning about Action I: A Possible Models Approach, *Artificial Intelligence* 35, 1988.
- M. Ginsberg and D. Smith Reasoning about Action II: The Qualification Problem, *Artificial Intelligence* 35, 1988.

- S. Hanks and D. McDermott, Nonmonotonic Logic, and Temporal Projection, *Artificial Intelligence*, vol. 33, pp 379-412, 1987. Classic paper on the Yale shooting problem.
- G. N. Kartha, Soundness and Completeness Theories for three Formalizations of Action, in *Proceedings of the Thirteenth International Joint Conference on Artificial Intelligence (IJCAI'93)*, pp 724-729, 193.
- G. N. Kartha and V. Lifschitz, Actions with Indirect Effects—Preliminary Report, in *Proceedings of the Fourth International Conference on the Principles of Knowkeledge Representation and Rasoning (KR'94)*, 1994.
- R. Kowlaski and M. Sergot, A Logic-Based Calculus of Events, *New Generation Computing*, 4:67-95, 1986. A classic paper on the event calculus—an alternative to the situation calculus.
- Vladimir Lifschitz, Towards a Metatheory of Action, in *Proceedings of the Second International Conference on the Principles of Knowkeledge Representation and Rasoning (KR'91)*, pp 376-386, 1991.

- Fangzhen Lin, Embracing Causality in Specifying the indirect Effects of Actions, in *Proceedings of the Fourteenth International Joint Conference on Artifici al Intelligence (IJCAI'95)*, 1995.
- Fangzhen Lin and Raymond Reiter, How to progress a Database, *Artificial Intelligence*, vol. 92, 1997.
- Fangzhen Lin and Yoav Shoham, Provably Correct Theories of Action", in *Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI'91)*, 1991.
- Norman McCain and Hudson Turner, A Causal Theory of Ramifications and Qualifications, in *Proceedings of the Fourteenth International Joint Conference on Artifici al Intelligence (IJCAI'95)*, 1995.
- John McCarthy and Patrick J. Hayes. Some philosophical problems from the standpoint of Artificial Intelligence. In Bernard Meltzer and Donald Michie, editors, *Machine Intelligence 4*. Edinburgh University Press, 1969. The classic paper on the situation calculus.

- Robert Moore, A Formal Theory of Knowledge and Action, in *Formal Theories of the Commonsense World*, Ablex, Norwood, NJ, 1985.
- Raymond Reiter, The Frame Problem in the Situation Calculus: A Simple Solution (Sometimes) and a Completeness Result for Goal Regression, in *Artificial Intelligence and Mathematical Theory of Computation: Paper in Honor of John McCarthy*, pp 359-380.
- Raymond Reiter, *Knowledge in Action: Logical Foundations for Describing and Implementing Dynamical Systems*, to appear, 2000. Draft available from `http://www.cs.toronto.edu/cogrobo/`.
- Erik Sandewall, *Features and Fluents*, Oxford University Press, 1994. Solid book but difficult to read.
- Murray Shanahan, *Solving the Frame Problem*, MIT Press, 1997.
- M. Shanahan, The Ramification Problem in the Event Calculus, in *Proceedings of the Sixteenth International Joint Conference on Artifici al Intelligence (IJCAI'99)*, 1999.
- Yoav Shoham, Chronological Ignorance: Time, Nonmonotonicity,

Necessity, and Causal Theories, in *Proceedings of the Fifthth National Conference on Artificial Intelligence (AAAI'86)*, pp 389-393, 1986.

- M Thielscher, Ramification and Causality, *Artificial Intelligence*, vol 89, 1997.
- Michael Thielscher, Fluent Calculus Tutorial, `http://pikas.inf.tu-dresden.de/~mit`.
- M. Winslett, Reasoning about Action using a Possible Models Approach, in *Proceedings of the Seventh National Conference on Artificial Intelligence (AAAI'88)*, 1988.
- Electronic Transactions on Artificial Intelligence pages on Nonomonotonic Reasoning and Change, `http://www.ida.liu.se/ext/etai/indexframe.html`.