How Much Does a Household Robot Need to Know in Order to Tidy up?

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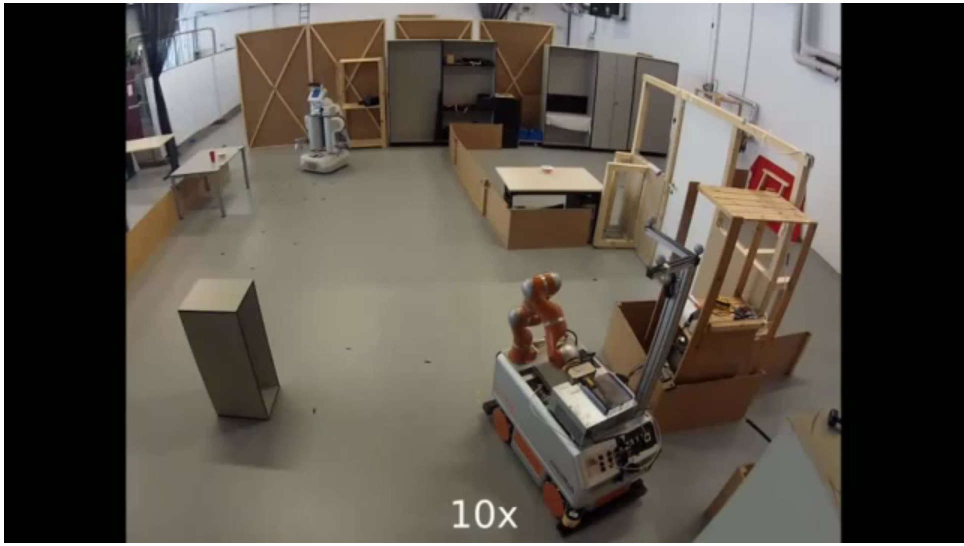
Outline

- Motivation
- Expanding universes
- Limited uncertainty
- Continual replanning vs. conditional planning
  - Soundness, completeness, complexity
- Conclusions & Outlook

Motivation: Tidy up

- Use plan-based agents
  - to anticipate the future
  - to compose behaviors / motor programs into complex action sets: **plans**
  - in order to achieve goals
- What should they *know* in order to generate and execute a plan?
- What kind of *planning technique* should they use?

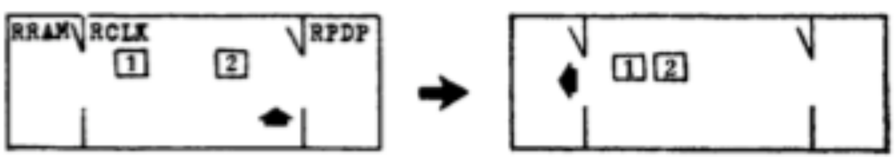


- *Classical planning*
  - is well researched
  - there are fast planning systems (TFD/M)

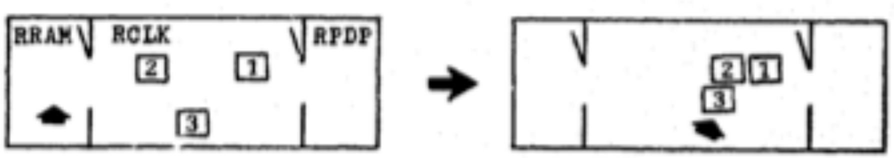
Historic Perspective

	PROBLEM 1	PROBLEM 2	PROBLEM 3	PROBLEM 4	PROBLEM 5
Without MACROPS					
Total time (minutes)	3 : 05	9 : 42	7 : 03	14 : 09	–
Time to produce MACROP	1 : 00	1 : 28	1 : 11	1 : 43	–
Time to find unlifted plan	2 : 05	8 : 14	5 : 52	12 : 26	–
Total nodes in search tree	10	33	22	51	–
Nodes on solution path	9	13	11	15	–
Operators in plan	4	6	5	7	–

Problem 1



Problem 4



From Fikes et al. (1972). Learning and executing generalized robot plans. *Artificial Intelligence* **3:** 251-288

Planning problem classes

- Domain: closed or open
- Effects: deterministic, non-deterministic, probabilistic
- Observability of the environment: complete, partial, not observable
- Horizon & Objective: …

➢ *Classical Planning*: closed domain, deterministic actions, complete observability (in the beginning), …

Household situations

- It is *not known* how many objects exist in the household (> 10000)
  - but the set of types of objects is fixed
- It is *not known* what states the objects are in
  - but the state can be observed when the robot is close to the object
- The outcomes of actions can vary (non-determinism)

➢ Classical planning is not adequate

What do we lose?

- There is *no planning system* for open domain, non-deterministic, partially observable planning
- Even if we do we away with open domains,
  - CltAltAlt, POND or MBP could be used
  - However, they are slow compared with e.g. TFD
- If we simplify the problem and use a classical planner:
  - What kind of reasoning do we lose?
  - Can we guarantee completeness / soundness under some conditions?
  - How hard is it to check such conditions?

A note about notation

- We will not use any particular planning formalism or language in this talk
- Think of PDDL extended by non-determinism and branching: *NPPDL*
- All pre-conditions (and goal conditions) are implicitly in the scope of a modal knowledge operator (most of the time)
  - single-agent logic!

Open domains

- In principle, we want a planning language with an open domain = countable number of objects of each type
- Current planners use propositionalization (grounding to propositional logic) in order to be efficient
- Planning with open domains is undecidable [Erol et al 95]
  - Turing machine with an unbounded number of tape cells could be simulated

Expanding universes

- Instead of an open domain, consider only the objects you know about

- If you detect a new object
  - add it to the domain
  - and replan with the new domain

- Seems reasonable, because our household robot is not supposed to simulate a Turing machine.

Completeness?

- What does completeness mean in this context?
  - If there is a plan under the open domain semantics, then there should be a sequence of plans generated by replanning over expanding universes such that the final one is successful.
- Clearly unachievable because of undecidabilty
- Unclear, how to formalize a guarantee for which we can achieve completeness

Soundness?

- Universal quantification in pre-conditions with open domain semantics can be problematic.
- However, universally quantified conditions make only sense if we quantify over known objects!
- Note:
  - You should know about all your tools!
  - Formulation of goal can be non-trivial, e.g.
    - *remove all known objects from all known tables*

Uncertainty (logical)

- Uncertainty is produced by
  - the initial state description
    - *The door is open or closed*
  - non-deterministic effects of actions
    - *Opening the door can be successful or not*
- Uncertainty is reduced by
  - observations / sensing actions
    - *Determine the state of the door*
  - (deterministic) action (possibly conditional) effects
    - *Closing the door*

Representing logical uncertainty

- Usually: *set of possible worlds*
- Drawback: exponential blowup wrt. single model (STRIPS) case

- Alternative: Use three-valued logic, where the third value means unknown
- You cannot represent anymore
  - Know(A ∨ B)
- but only
  - Know(A) ∨ Know(B)

What do we lose?

- Possible world semantics is necessary for reasoning by case over conditional action effects:
  - Initially *Know(A ∨ B)*
  - Action to make *A* true if *B* was true:
    - *B* false: then *A* must be true
    - *B* true: then A will now be true
  - Similar: Sensing *¬B*
  - ➢ *Know(A)*
- Not possible with three-valued logic!

➢ Does a household robot need to have diagnostic reasoning capabilities

Completeness / Soundness

- The original problem is 2-EXP-complete, while planning with a three-valued logic and sensing is EXP-complete.
- We clearly lose completeness!
  - We cannot deal with hidden variables
- However, soundness is preserved: Any plan under the possible world semantics is a valid plan under the three-valued semantics!

Limited observability & monotonicity

- The only way to acquire knowledge about the truth value of as fluent is to sense it
- Observability is limited: sensing actions may have preconditions, e.g., being close to the relevant object

- By sensing we monotonically decrease uncertainty
- Non-deterministic actions might increase it, but we can assume that by monitoring no new uncertainty is generated

Conditional planning/Policies

- We still have sensing action outcomes that are unknown at planning time
  - Can be viewed as a special kind of non-determinism
- Plans are branching plans or policies
- What is a valid plan?
  - *Strong plan*: Cycle-free plan that guarantees success regardless of the sensing outcomes
  - *Strong cyclic plan:* Possibly cyclic plan that guarantees that the goal is always reachable
  - *Weak plan:* Sequence of actions/observations that lead to the goal

Continual planning

- Instead of planning for every contingency, generate an "optimistic" plan
- Monitor execution and replan if necessary
  - Generate policy online

- Actually, this is an approach many people have taken
- For example: Probabilistic planners are outperformed by FF-replan (IPC-04 & -06)
  - on "probabilistically uninteresting" domains
- Question: What are we losing?

Completeness & soundness

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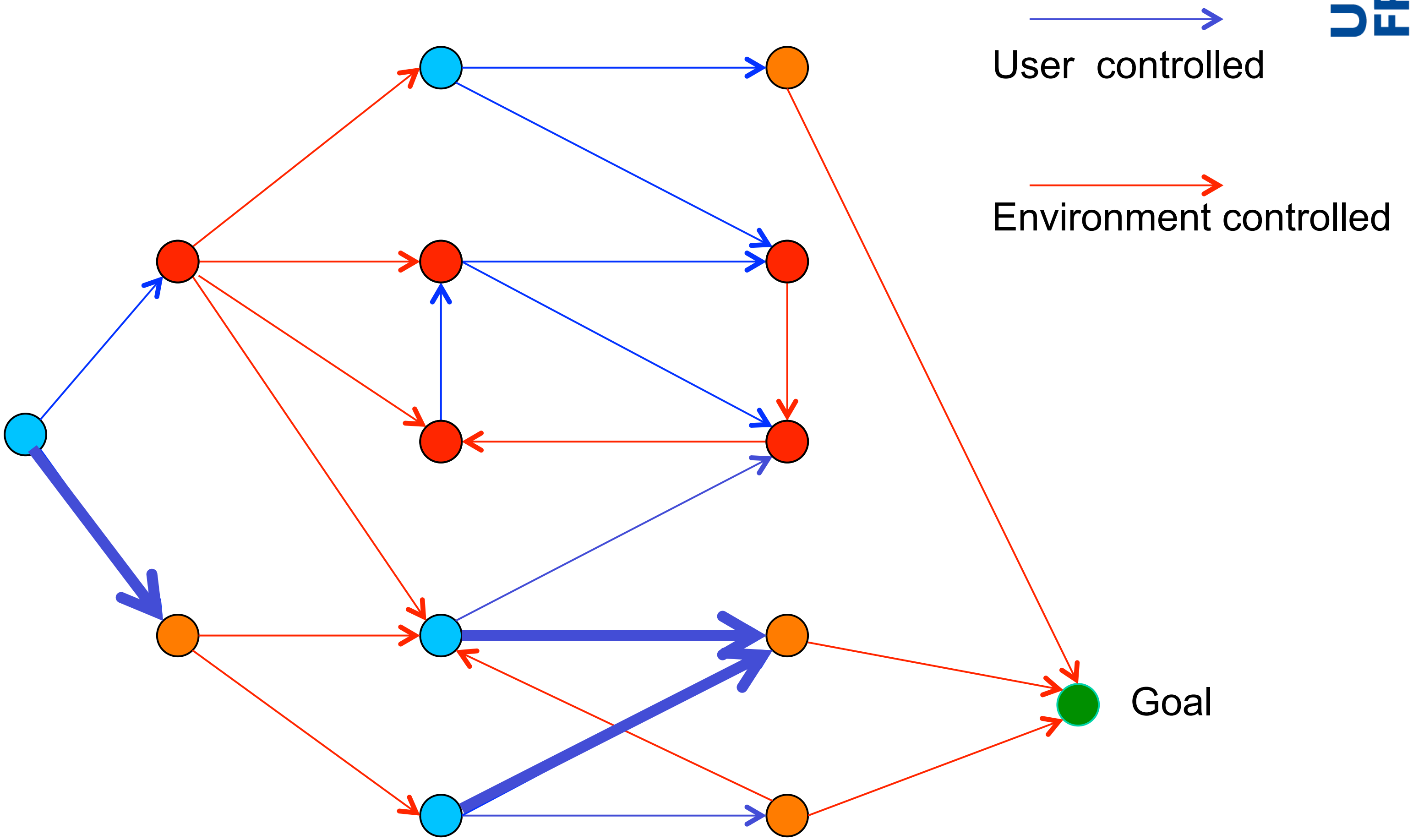
- Completeness: For every cyclic strong plan, for every state reachable in the strong cyclic plan:
  - the replanning approach is able to generate a successful linear plan
    - *Easy,* just create a weak plan
- Soundness: At each state, create only a successful plan with the correct prefix action,
  - if there is strong cyclic plan with the appropriate action.
    - *Hard,* actually as hard as non-deterministic planning, i.e. EXP-hard

Conditions for soundness

- Invertability: Everything can be undone
  - Very strong and unrealistic but easy to check
    - household robots might want to throw things into the garbage can
- Strongly connected state space: every state is reachable from every other state by weak plans
  - Weaker, but still very strong and less easy to check
- Dead-end free: We can never reach a state from which no goal state is reachable
  - Realistic, but hard to check

Dead-ends visually



Checking for dead ends

- Algorithm for checking for presence of dead end from initial state *i*
  1. Guess state *s*
  2. Check whether *s* is reachable by a weak plan from initial state *i*
  3. Check that there is no weak plan from *s*

- Step 2 can be done in PSPACE (for prop. planning)
- The complement of step 3 can be checked in PSPACE
- Since PSPACE is closed under non-determinism and complement, checking is in PSPACE!
- ➢ Checking for dead ends is not harder than classical planning

Conclusion

- We reduced non-deterministic, partial observable, open domain planning to classical planning, sacrificing
  - completeness, but only for puzzle mode reasoning
  - a little bit of soundness, but we can provide guarantess
- We have specified a PSPACE checkable criterion for soundness preservation
- The sacrifices all seem to preserve the functionality of a household robot

Possible improvements & challenges

- Provide empirical justifications for the claims about efficiency, i.e.,
  - compare nondeterministic, partially observable domain planners with continual classical re-planners
- Implement checkers/provers that prove dead-end freeness of a given domain
- Find other characterizations of domains preserving soundness
- Find ways to mediate between classical replanning and full nondeterministic conditional planning (get inspiration from circuit diagnosis)