Encoding Planning Problems as Propositional Logic Satisfiability

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16.410-13
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Assignment

- Remember:
  - Problem Set #6 Propositional Logic, due next Wednesday, October 27th.
  - 16:413 Project Part 1: Sat-based Activity Planner, due Wednesday, November 3rd.
- Reading
  - Today: [AIMA] Chapter 10, re-read sections on SatPlan.
  - Monday: Johan de Kleer and Brian C. Williams, "Diagnosing Multiple Faults," *Artificial Intelligence*, 32:100-117, 1987.

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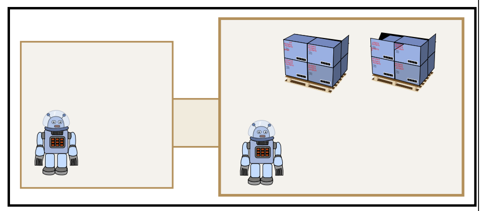
Planning problem

- Recall the planning problem:
  - Objects
    - *robot1, robot2, load1, load2, room1*
  - Predicates describing properties of objects
    - *(IN ?robot ?room), (HAS ?robot ?load)*
  - Actions as means to change these properties
    - *Navigate (?robot, ?room_from, ?room_to)*
  - Initial condition
  - Goal statement



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Propositional logic SAT problem

- Recall the SAT problem:
  - Given a set of clauses, find an assignment to all propositions to satisfy all the clauses.

$$p_1 \vee \neg p_2 \vee p_3$$
$$\neg p_1 \vee \neg p_2 \vee p_4$$
$$\neg p_3 \vee p_4 \vee p_5$$

- SAT solvers are very powerful.
    - Can process problems with tens of thousands of variables

Encoding planning as SAT

- Idea:
  - Define propositions for predicates and decisions
  - Encode problem description in propositional logic

$$\text{initial state} \wedge \text{all possible action descriptions} \wedge \text{goal}$$

Encoding planning as SAT

- **Initial condition**
- Encode the truth of predicates:

$$(\text{IN robot1 bedroom})^0 \wedge (\text{IN robot2 kitchen})^0$$

- Remember to include those that are false:

$$\neg(\text{IN robot1 kitchen})^0 \wedge \neg(\text{IN robot2 bedroom})^0$$

Encoding planning as SAT

- **Actions**
- Straightforward approach:
  - One proposition for each action:
    $\text{Navigate(robot1 bedroom kitchen)}^0$
  - True if robot *navigates* from *bedroom* to *kitchen* at time 0

$$(\text{IN robot1 kitchen})^1 \Leftrightarrow$$
$$((\text{IN robot1 kitchen})^0 \wedge \neg(\text{Navigate(robot1, kitchen, bedroom)}^0 \wedge (\text{IN robot1 kitchen})^0))$$
$$\vee(\text{Navigate(robot1, bedroom, kitchen)}^0 \wedge (\text{IN robot1 bedroom})^0))$$

Robot was in the kitchen at time 0 and did not leave the kitchen at time 0.
Robot was in the bedroom at time 0 and left the bedroom to go to kitchen at time 0.

Encoding planning as SAT

- **Actions**
- What may go wrong?
  $\text{Navigate(robot1, kitchen, bedroom)}^0$
  – However, robot1 is not in the kitchen at time 0 !
- *Precondition axioms:*
  $\text{Navigate(robot1, kitchen, bedroom)}^0 \Rightarrow (\text{IN robot1 kitchen})^0$

Encoding planning as SAT

- **Actions**
- What else may go wrong?

$$\text{Navigate(robot1, kitchen, bedroom)}^0$$
$$\text{Navigate(robot1, bedroom, livingroom)}^0$$

- Ensure that one action can be taken at a time:

$$\neg(\text{Navigate(robot1, kitchen, bedroom)}^0 \wedge \text{Navigate(robot1, bedroom, livingroom)}^0)$$

Encoding planning as SAT

- **Outline of the algorithm**:
  - Check satisfiability for increasing number of steps

i = 1

If satisfiable for i steps then

    construct the solution

Else

    i = i + 1

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