Planning and Acting under Uncertainty

Dra. Mª Dolores Rodríguez Moreno

Objectives

Specific Objectives

- Nondeterministic models
- Techniques to plan and act under uncertainty

Source

- Stuart Russell & Peter Norvig (2009). Artificial Intelligence: A Modern Approach. (3rd Edition). Ed. Pearsons
- Dana Nau's slides for Automated Planning. Licensed under https://creativecommons.org/licenses/by-nc-sa/2.0/

Outline

- **Motivation**
- Introduction
- Replanning
- Contingency Planning
- Probabilistic Planning
- Conclusions

Motivation (I)

- Deterministic models assume complete knowledge
  - Initial State
  - Effects of actions
- Real problems
  - Unexpected events can occur
  - Actions can have unexpected outcomes
  - State of the world may not be known with certainty
- Nondeterministic models predict alternative options
  - An action when applied in a state may result in one among several possible states
- Which model to use? Design choice

Motivation (II)

- i.e: the execution of an action may fail
- A deterministic model:
  - Model the nominal case (in which failure does not occur)
  - Monitor execution
  - Detect failure when it occurs
  - Recover by replanning or re-acting with some failure-recovery mechanism
- Non deterministics model:
  - Take into account all the different possible outcomes
  - May become much more complicated (conceptually & computationally)

Motivation (III)

- i.e. throw of a dice or in the toss of a coin or in a sensing action of a robot?
- Model the nominal case in not an option
- Only non-determinism is posible and can consider all possibilities
- Models may not be perfect
  - Even if we model the six outcomes of the throw of a dice the tossed dice might run off the playing board, and end up under the table
  - The robot spills water breaking its own circuit

Outline

- Motivation
- **Introduction**
- Replanning
- Contingency Planning
- Probabilistic Planning
- Conclusions

Introduction (I)

- Planning and acting with nondeterministic models is more challenging:
  1. The search space is no longer represented as a graph, is an And/Or graph
  2. Plans cannot be restricted to sequences of actions, need to generate conditional plans
  3. The definition of solution plan is not trivial: chances of achieving a goal

Introduction (II)

- **Online planning** and **replanning** for unknown environments
- **Contingency planning** for partially observable and nondeterministic environments
- **Sensorless planning** (also known as **conformant planning**) for environments with no observations

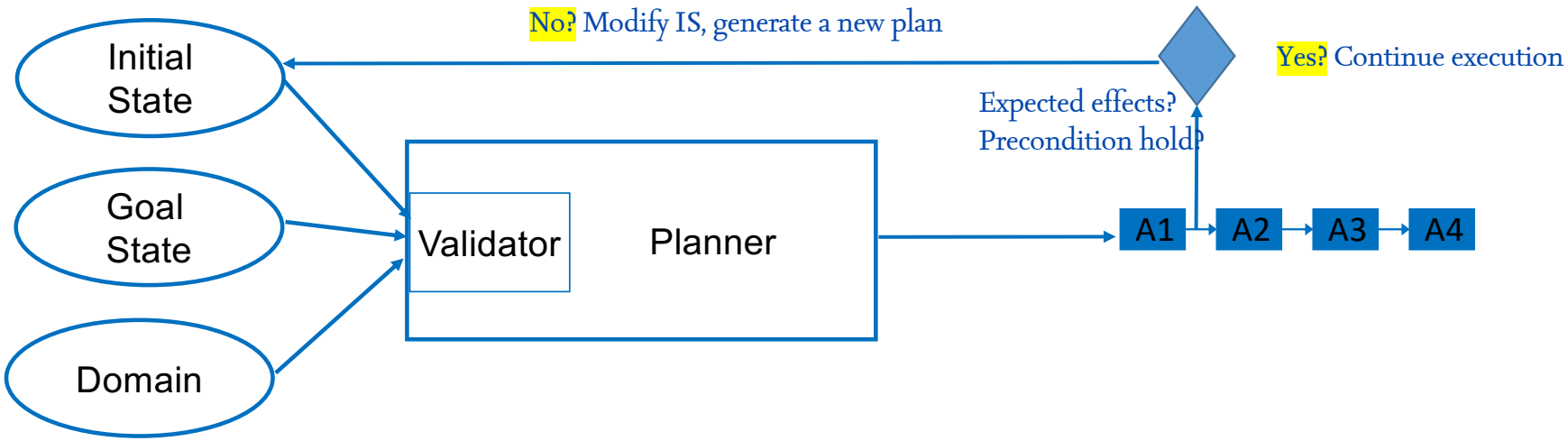
Outline

- Motivation
- Introduction
- **Replanning**
- Contingency Planning
- Probabilistic Planning
- Conclusions

Replanning (I)

- Interleaving deliberation & execution is effective strategy to tackle nondeterminism and incomplete knowledge but needs replanning
- How carefully to monitor the environment?
  - **Action monitoring**: before executing an action, the agent verifies that all the preconditions still hold
  - **Plan monitoring**: before executing an action, the agent verifies that the remaining plan will still succeed
  - **Goal monitoring**: before executing an action, the agent checks to see if there is a better set of goals it could be trying to achieve

Replanning (II): action monitoring



Outline

- Motivation
- Introduction
- Replanning
- **Contingency Planning**
- Probabilistic Planning
- Conclusions

Contingency Planning (I)

- Construct a conditional plan ≠ with branches for ≠ contingencies
- Partially observable and nondeterministic environments
- Classical approach
  - Produce plans even if the initial conditions and the outcomes of some of the actions are not known
  - A plan contains actions that may or may not actually be executed, depending on the circumstances that hold at the time
  - Each time an action with an uncertain outcome is added to the plan the planner tries to achieve the goal for each different outcome of the action
  - Expensive if not simple domain

Contingency Planning (II)

- Precautionary Planning
  - Generate a high probability seed plan, which is then augmented with contingency branches to handle the most critical action outcomes
  - Any remaining outcomes will be handled by runtime replanning
  - The resulting contingent plan achieves at least a given probability threshold
  - Interleave planning and execution
  - Takes the advantage of the speed of replanning but considers the potencial unrecoverable failures and attemps to avoid them

Outline

- Motivation
- Introduction
- Replanning
- Contingency Planning
- **Probabilistic Planning**
- Conclusions

Probabilistic Planning

- Describes uncertainty by probability distributions
- Assumes results of actions fully observable
- Representation: PPDDL
  - Action: same as PDDL with probabilistic outcomes on actions
  - Probabilities on initial conditions

Techniques (I)

1. Solving Markov Decision Processes (MDP)
   - Construction of a policy using value or policy iteration or
   - Heuristically guided forward state space search
   - Take into account all potential actions
   - Robust plans but expensive
2. Using planning graph models
   - To compute estimates of probability of propositions and actions
   - Guide a planner toward the most likely plan for achieving the goals

Techniques (II)

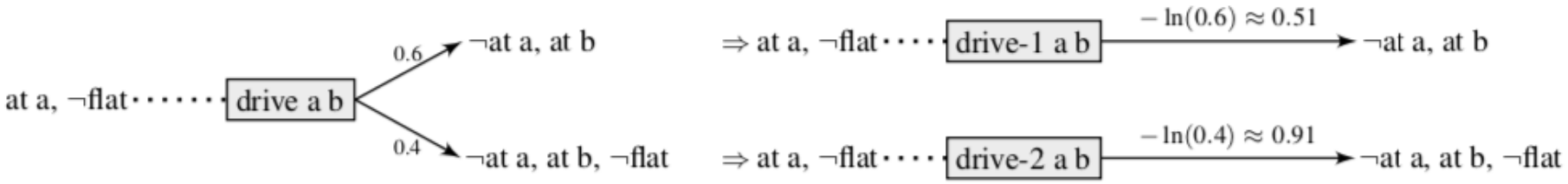
3. Translation into deterministic planning problems
   - Translate the problem into a classical one, then solved by classical planner
   - Deal with uncertainty in the initial state, not in the actions' outcomes
   - Deal with disjunctive uncertainty not probabilistic uncertainty
4. **Determinization**
   - Transform the given probabilistic problem into a deterministic one
   - Use heuristic based on relaxed plans to guide a deterministic planner
   - Generate solution executed until observed state differs from what's expected
   - If this happens, then re-planning

Determinization: PPDDL example

```
(:action drive
        :parameters (?trk - truck ?from - location ?to - location)
       :precondition (and (connected ?from ?to) (at ?from ?trk) (not (flattire)))
        :effect (and (not (at ?from ?trk)) (at ?to ?trk)
                     (probabilistic 0.4 (flattire))))
(:action get-tire
        :parameters (?trk - truck ?l - location)
        :precondition (and (at ?l ?trk) (spare ?l))
        :effect (and (not (spare ?l)) (hasspare)))
(:action change
        :precondition (hasspare)
        :effect (and (not (hasspare)) (not (flattire))))
```

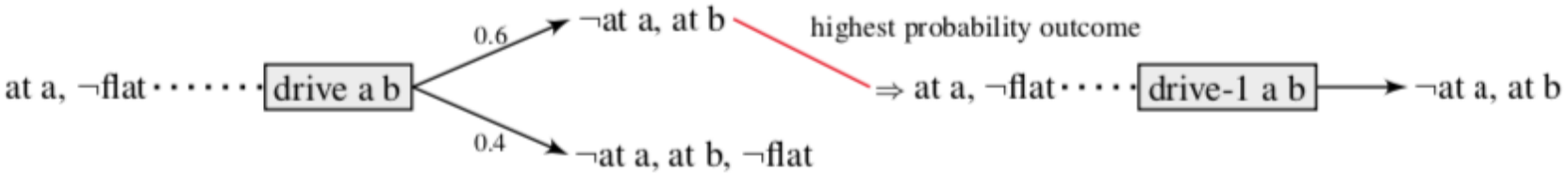
Determinization (I)

- Generate a deterministic action for each probabilistic effect
- The probability of its outcomes is transformed into an additive cost
  - $C_i = -Ln(P_i)$
  - Use a numeric planner



Determinization (II)

- Use heuristic functions based on relaxed plans to guide a deterministic planner in the search for a deterministic plan
- Do not make use of probabilistic information
- Figure shows *Single-outcome determinization*



Outline

- Motivation
- Introduction
- Replanning
- Contingency Planning
- Probabilistic Planning
- **Conclusions**

Conclusions

- Dropped the unrealistic assumption of determinism
- Presented different ways to handle with uncertainty
- FF-Replan won IPC'04 & 06 in Probabilistic track