INF5390 – Kunstig intelligens

Planning and Acting

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Outline

- Planning and scheduling
- Hierarchical task networks
- Conditional planning
- Monitoring and replanning
- Multi-agent planning
- Summary

AIMA Chapter 11: Planning and Acting
in the Real World

Planning in ideal and real worlds

- Classical planners assume
  - √ Fully observable, static and deterministic domains
  - √ Correct and complete action descriptions
  - √ … allowing a “plan-first-then-act” planning approach
- … but in the real world
  - √ The world is dynamic, and *time* cannot be ignored
  - √ Information on the world is incomplete and incorrect
  - √ … the agent must be prepared for unexpected events
- Plus - scaling up to real-world problem size!

Time, schedules, and resources

- The PDDL language allows events (actions) and ordering of events, but not time *duration*
- In real-life planning, we must take duration, delays, etc. into account (not just ordering)
- *Job shop scheduling*:
  - The problem is to complete a set of jobs
  - Each job consists of a set of actions, with given duration and resource requirements
  - Determine a schedule that minimizes total time *(makespan)* needed while respecting resource constraints
- Must extend representation language to express duration and resource constraints

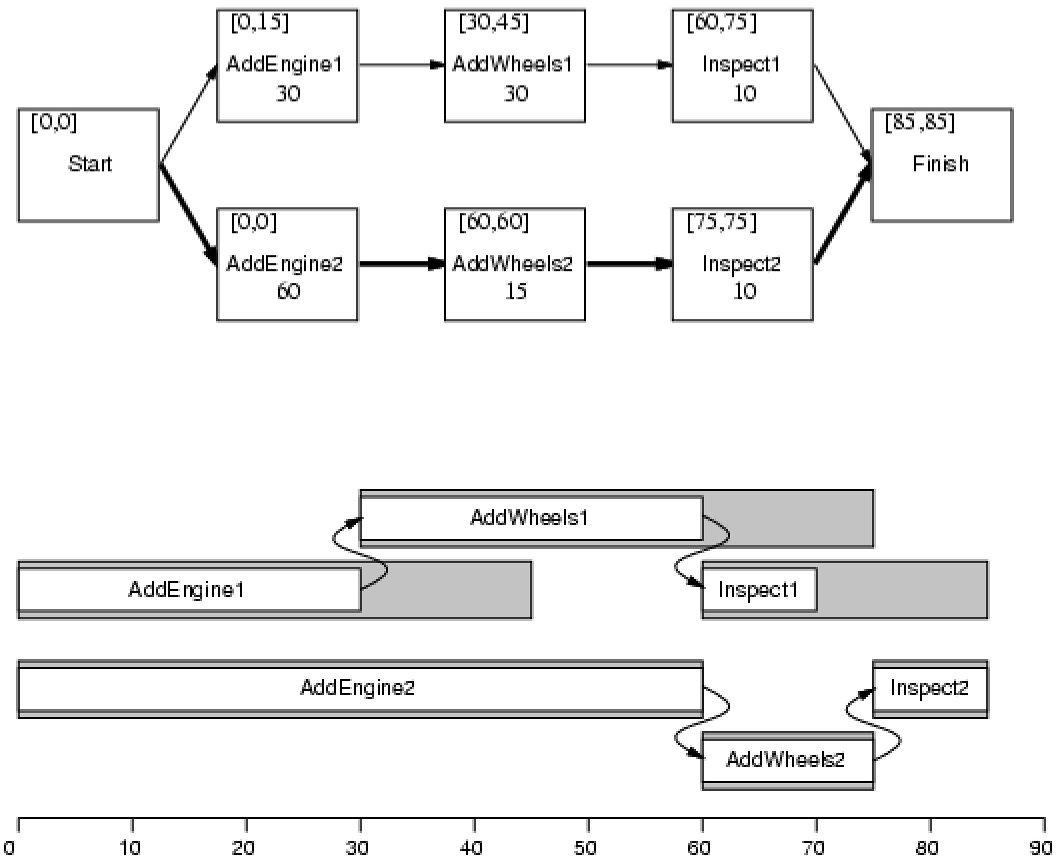
Example - Assembling two cars

- ***Jobs***(*{AddEngine1 < AddWheels1 < Inspect1},*
  {AddEngine2 < AddWheels2 < Inspect2})
- ***Resources***(*EngineHoists(1), WheelStations(1),*
  Inspectors(2), LugNuts(500))
- ***Action***(*AddEngine1,* DURATION:30,
  USE: *EngineHoists(1))*
- ***Action***(*AddEngine2,* DURATION:60,
  USE: *EngineHoists(1))*
- ***Action***(*AddWheels1,* DURATION:30,
  CONSUME: *LugNuts(20),* USE: *WheelStations(1))*
- ***Action***(*AddWheels2,* DURATION:15,
  CONSUME: *LugNuts(20),* USE: *WheelStations(1))*
- ***Action***(*InspectI,* DURATION:10,
  USE: *Inspectors(1))*

Scheduling - No resource constraints

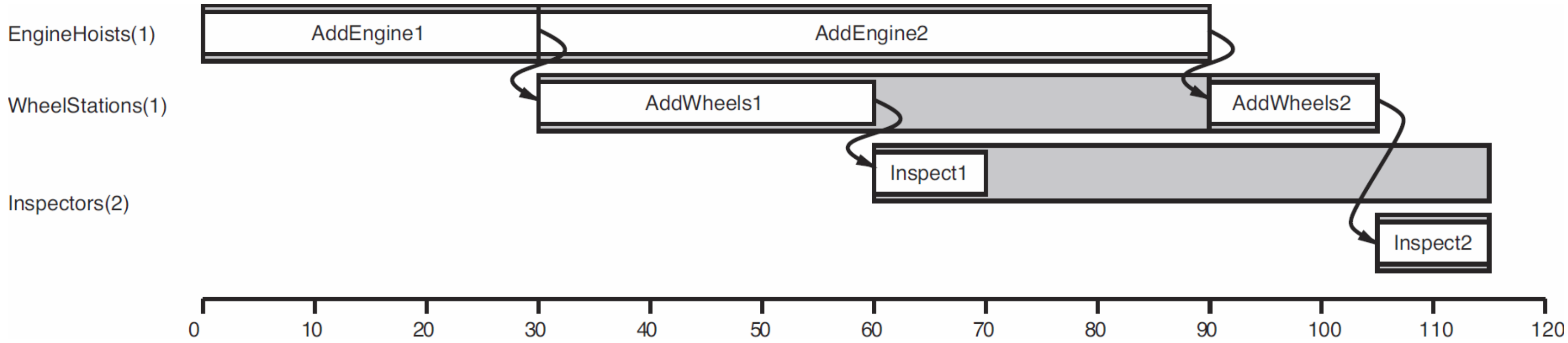
- Partial order plan produced by e.g. POP
- To create a *schedule,* we must place actions on a timeline
- Can use *critical path* method (CPM): the longest path, no slack – determines total duration
- Shortest duration schedule, given partial-order plan:

  85 minutes



Scheduling with resource constraints

- Actions typically require resources
  - √ *Consumable* resources – e.g. *LugNuts*
  - √ *Reusable* resources – e.g. *EngineHoists*
- Resource constraints make scheduling more complex because of interaction between actions
- AI and OR (Operations Research) methods can be used to solve scheduling problems with resources
- Shortest duration gone up from 85 to 115 minutes

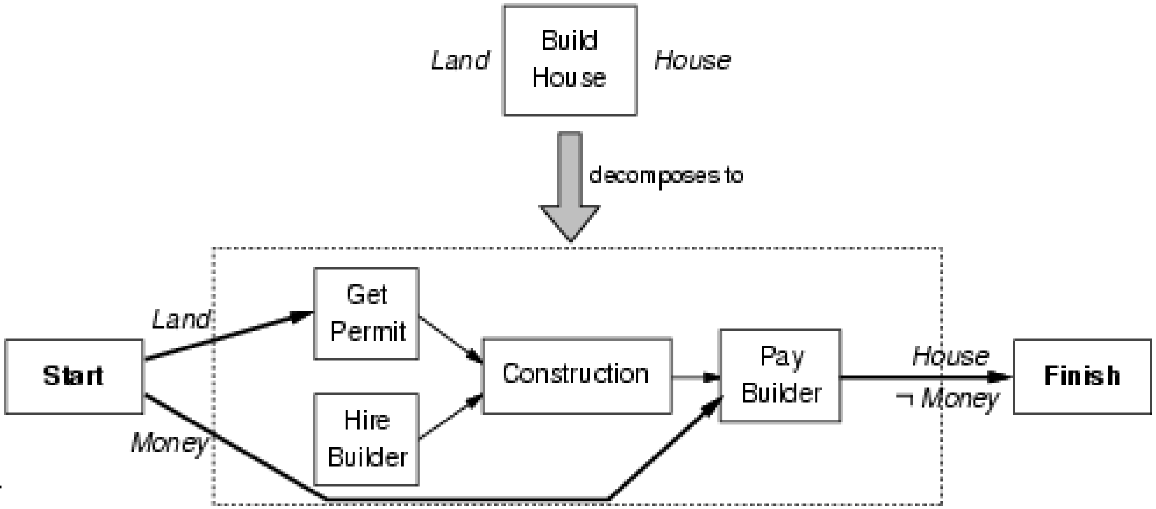


Planning and scheduling

- The approach shown here is common in real-world AI applications for manufacturing scheduling, airline scheduling, etc. :
  - First generate partial order plan without timing information (*planning*)
  - Then use separate algorithm to find optimal (or satisfactory) time behavior (*scheduling*)
- In some cases it may be better to *interleave* planning and scheduling, e.g. to consider temporal constraints already at the planning stage

Reduce complexity by decomposition

- Often possible to reduce problem complexity by decompose to subproblems, solve independently, and assemble solution
- HTN – Hierarchical Task Networks
  - Planner keeps library of subplans
  - Extend planning algorithm to use subplans
  - Can reduce time&space requirements considerably
- Most real-world planners use HTN variants



Planning in nondeterministic domains

- Nondeterministic worlds
  - √ *Bounded* nondeterminism: Effects can be enumerated, but agent cannot know in advance which one will occur
  - √ *Unbounded* nondeteminism: The set of possible effects is unbounded or too large to enumerate
- Planning for bounded nondeterminism
  - √ Sensorless planning
  - √ Contingent planning
- Planning for unbounded nondeterminism
  - √ Online replanning
  - √ Continuous planning

Sensorless planning

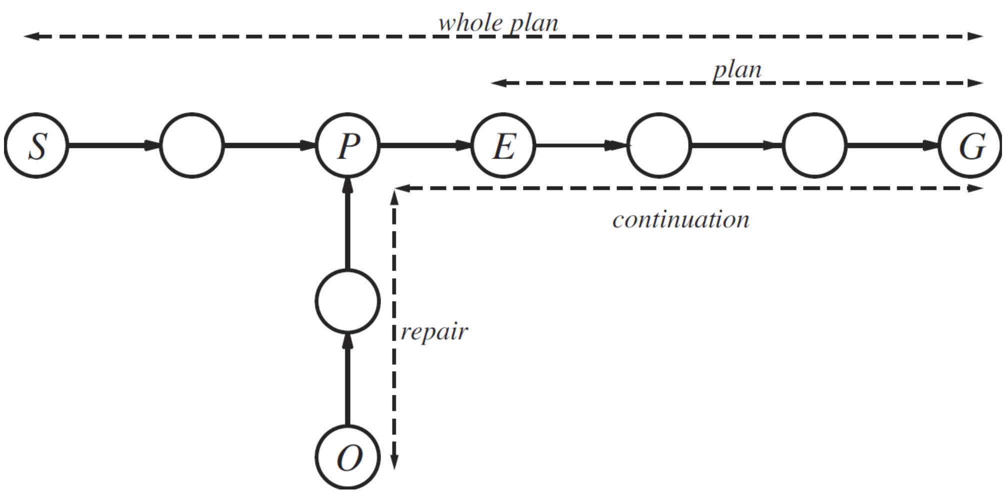
- Agent has no sensors to tell which state it is in, therefore each action might lead to one of several possible outcomes
- Must reason about *sets* of states (belief states), and make sure it arrives in a goal state regardless of where it comes from and results of actions
- Nondeterminism of the environment does not matter – the agent cannot detect the difference anyway
- The required reasoning is often not feasible, and sensorless planning is therefore often not applicable

Contingent planning

- Constructs conditional plans with branches for each (enumerable) possible situation
- Decides which action to choose based on special sensing actions that become parts of the plan
- Can also tackle partially observable domains by including reasoning about belief states (as in sensorless planning)
- Planning algorithms have been extended to produce conditional branching plans

Online replanning

- Monitors situation as plan unfold, detects when things go wrong
- Performs replanning to find new ways to reach goals, if possible by repairing current plan



- Agent proceeds from S, and next expects E following original *whole-plan*
- Detects that it's actually in O
- Creates a *repair* plan that takes it from O to a state P in original plan
- New plan to reach G becomes *repair + continuation*

Contingent planning vs. replanning

- Contingent planning
  - All actions in the real world have additional outcomes
  - Number of possible outcomes grows exponentially with plan size, most of them are highly improbable
  - Only one outcome will actually occur
- Replanning
  - Basically assumes that no failure occurs
  - Tries to fix problems as they occur
  - May produce fragile plans, hard to fix if things go wrong

Continuous spectrum of planners

- Contingent planning and replanning are extremes of a spectrum, where intermediate solutions exist
  - √ Disjunctive outcomes for actions where more than one outcome is likely
  - √ Agent can insert sensing action to detect what happened and construct corresponding conditional plan
  - √ Other contingencies dealt with by replanning
- More generally, agents in complex domains and with incomplete/incorrect information should
  - √ Assess likelihood and costs of various outcomes
  - √ Construct plan that maximizes probability of success and minimizes cost
  - √ Ignore contingencies that are unlikely or easy to deal with

Continuous planning

- The planner persists over time – never stops, and interleaves planning, sensing and execution
- The continuously planning agent must
  - Execute steps of current plan (even if not complete)
  - Refine plan if not applicable or in conflict
  - Modify plan in light of new information
  - Formulate new goals when required
- Planners, e.g. partial-order planning (POP) can be extended to provide required functionality

Multi-agent planning

- Single-agent planning works against ”nature”, but in many cases the environment includes other agents with their own goals
- Multi-agent environments can be
  - √ *Cooperative*: Agents work together to achieve some common goal
  - √ *Competitive*: Agents have conflicting goals
- Multi-agent architectures and applications, incl. planning, represent very active AI research area

Coordination of multi-agent planning

- Cooperative planning can produce *joint plans*
  - For each agent, the joint plan tells what to do
  - If each follows its plan, overall goal will be achieved
- Problems arise if several joint plans are possible
  - Each agent must know which plan to follow
  - Requires some form of *coordination*
- Coordination can be by
  - Convention or *social law*
  - Inter-agent *communication*

Summary

- Classical planning systems assume deterministic and static domains, and complete and correct information. Many domains violate this assumption
- *Scheduling* is planning with time and resource constraints and are solved by special methods
- Large planning problems can be made tractable by *hierarchic decomposition* (hierarchic task networks)
- Nondeterministic domains can be *bounded* (enumerable outcomes) or *unbounded* (any outcome is possible)

Summary (cont.)

- Planning in bounded determinism includes *sensorless planning* (make sure plan succeeds) or *contingent planning* (select one of multiple pre-made plans bases on sensing)
- Planning in unbounded nondeterminism includes *online replanning* (repair plan if failure) or *continuous planning* (ongoing adaptation of plan)
- *Multi-agent planning* applies to domains where there are other *cooperative* or *competitive* agents