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*INF5390 – Kunstig intelligens*

# **Planning and Acting**

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# Outline

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- 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

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- 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

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- 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

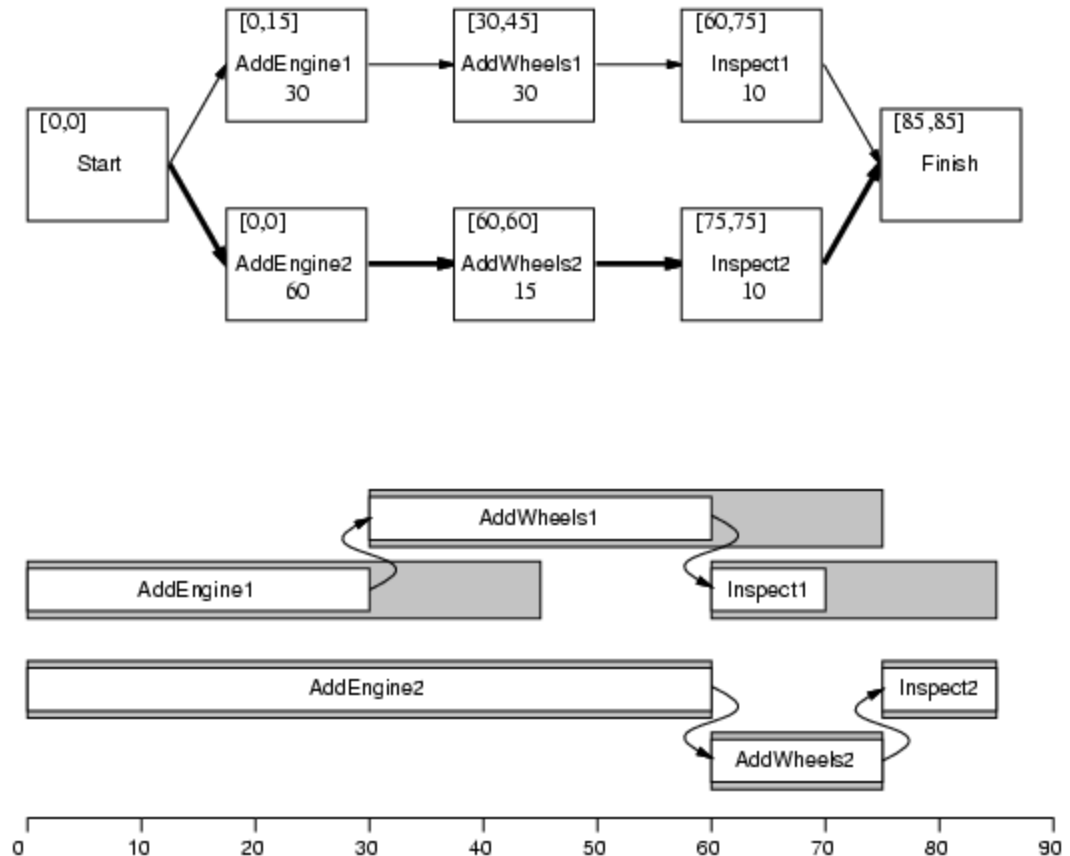
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- **Jobs**(*{AddEngine1 < AddWheels1 < Inspect1},*  
*{AddEngine2 < AddWheels2 < Inspect2}*)
  - **Resources**(*EngineHoists(1), WheelStations(1),*  
*Inspectors(2), LugNuts(500)*)
  - **Action**(*AddEngine1, DURATION:30,*  
*USE: EngineHoists(1)*)
  - **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)*)
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# Scheduling - No resource constraints

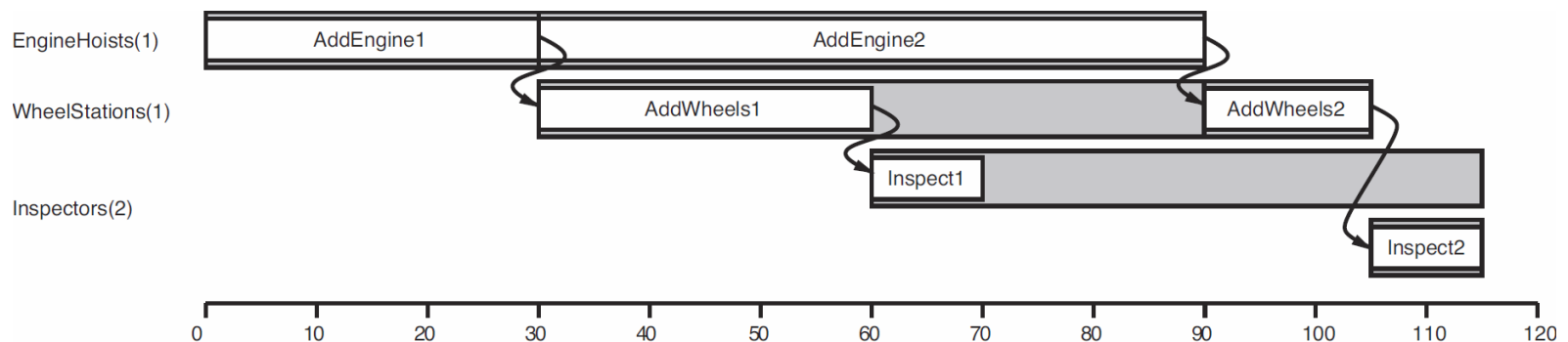
- Partial order plan produced by e.g. POP
- To create a *schedule*, we must place actions on a timeline
- Can use *critical path* method (CPM): the longest path, no slack – determines total duration
- Shortest duration schedule, given partial-order plan:

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

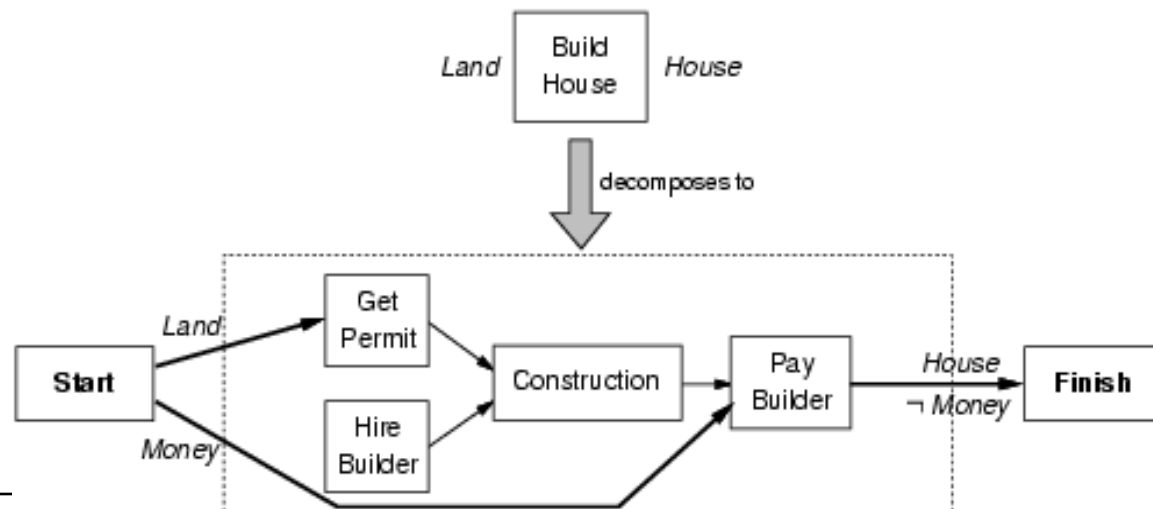
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- The approach shown here is common in real-world AI applications for manufacturing scheduling, airline scheduling, etc. :
  - ✓ First generate partial order plan without timing information (*planning*)
  - ✓ Then use separate algorithm to find optimal (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

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- Nondeterministic worlds
  - ✓ *Bounded* nondeterminism: Effects can be enumerated, but agent cannot know in advance which one will occur
  - ✓ *Unbounded* nondeterminism: 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

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- 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

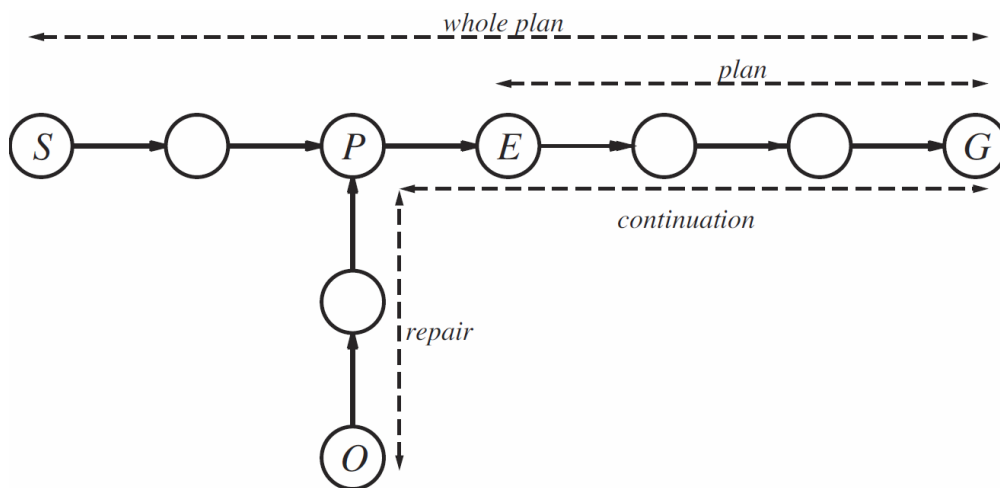
# Contingent planning

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- 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

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- 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

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- 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

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- 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

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- 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

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- 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

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- 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.)

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- 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